SPGR Sub-Project Completion Report

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Coordinated Project
on

Carbon Sequestration in Soils of Bangladesh: BRRI Component

April, 2010-June, 2014

Executing Organization

Soil Science Division
Bangladesh Rice Research Institute
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ABBREVIATION

AEZ= Agro-ecological zone
AWD= Alternate wetting and drying
BARC=Bangladesh Agricultural Research Council
BRRI=Bangladesh Rice Research Institute
C=Carbon
CD= Cow dung
CO_2 = Carbon-di-oxide
CSW= Continuous standing water
DAT=Days after transplanting
FRG = Fertilizer Recommendation Guide
GPS= Geographical Position System
H/Q = Head Quarter
HL= High Land
HRD=Human resource development
IPNS= Integrated Plant Nutrition System
LL= Low Land
MD = Member-Director
MHL=Medium High Land
MLL= Medium Low Land
MT= Minimum tillage
MV= Modern variety
NATP=National Agricultural Technology Project
NRM= Natural Resource Management
OC= Organic carbon
PCR=Project Completion Report
PI=Principal Investigator
PIU=Project Implementation Unit
PM=Poultry manure
RCBD= Randomized complete block design
RR= Rice root
RS=Rice straw
SOC= Soil organic carbon
STB= Soil Test Basis
STDEV= Standard Deviation
T. Aman = Transplanted Aman
TT= Traditional tillage
VLL= Very Low Land

Executive Summary

Coordinated Project on Carbon Sequestration in Soils of Bangladesh: BRRI Component, a sponsored public goods research project, received funding from the NATP: Phase1, Bangladesh Agricultural Research Council. This Project (BRRI Component) officially launched on 18 April 2010 and continued up to 30 June 2014. The project received an approval of budget Tk. 66, 46,221/-. The study was under taken to document existing carbon stock in soils of thirty AEZs in Bangladesh, to determine the effects of tillage operations and rice straw management in sequestering maximum C in soils, and different organic manures/residues and fertilizer management on carbon sequestration under rice – rice cropping pattern.

The existing carbon (C) stocks in soils of Bangladesh were assessed in the experiment no. 1. Upto date BRRI has been collected a total of 2188 soil samples from 10 AEZs (AEZ 1-10) out of 2400 samples from 10 AEZs. In general, the soil organic carbon SOC (%) decreased with the increase in soil depth irrespective of land types. The SOC (%) was found higher in the lowland than in the medium highland and highland. The SOC stock (t/ha) at 0-20 cm depth was higher in lowland (except AEZ-1) compared to medium highland and highland soil in irrespective of AEZs. Among the 10 AEZs, the highest SOC stock (t/ha) was found in AEZ-1 irrespective of land types.

Pot experiment (experiment no. 2) was conducted in the laboratory using different organic residues in soil to quantify CO_2 emission under two moisture regimes without rice crop. The rate of CO_2 emission was higher in earlier stage of incubation irrespective of organic sources in both flooding and moist condition. However, among the organic materials poultry manure emitted more CO_2 than cow dung, rice straw and rice root alone. During 129 days of incubation the total amount of CO_2 released from poultry manure containing pot was 1.5 g/kg, while it was 0.6 g/kg under the control (only soil) treatment.

The experiment no. 3 (with rice crop) was conducted at net house of BRRI H/Q taking four different organic residues, five carbon rates and two moisture regimes to determine the changes of SOC (%) under alternate wetting and drying (AWD) and continuous flooding condition with rice crop. At 30 and 60 days of incubation the poultry litter was found more efficient to increase the soil pH level significantly than others. On the other hand at180 days of incubation it was found that poultry litter, cow dung and rice straw showed significantly higher effect to increase soil pH than rice root. It was found that the soil pH increased more when the carbon rate was more i.e. 1.5 and 2.0 t C/ha. The SOC (%) decreased slightly with increasing the crop growth duration due to increasing temperature irrespective of all residues and carbon rates. Continuous standing water (CSW) condition was found more efficient to accumulate SOC (%) in soils.

Carbon sequestration in soils under different tillage operations and rice straw management practices was assessed in the experiment no. 5 in five consecutive rice seasons of T. Aman and Boro to quantify C sequestration and CO_2 emission taking two tillage operations and three levels of rice straw management practices. The significantly highest total organic carbon stock in soil (36 t/ha) was observed in Traditional tillage X RS mulch treatment. Rice straw surface mulch released higher amount (4420 kg/ha/114 days) of carbon dioxide over the control (3969 kg/ha/114 days) in T. Aman season while in Boro season rice straw incorporation released higher amount (3690 kg/ha/112 days) over the control (3288 kg/ha/112 days)

The effect of different organic materials and fertilizer management practices on carbon sequestration under rice-rice cropping pattern was quantified in the experiment no. 6. Application of organic materials with integrated plant nutrition system emitted much more carbon dioxide than soil test based chemical fertilizer in both seasons. Among the organic materials CO_2 emission was higher in cow dung and poultry manure treated plots compared to rice straw treated plot. The total CO_2 emission was highest in poultry manure treated plots (4943 kg/ha/114 days in T. Aman & 4315 kg/ha/112 days in Boro) and the lowest was in control (3605 kg/ha/114 days in T. Aman & 2955 kg/ha/112 days in Boro). Soil organic carbon status in post harvest soil showed slightly increasing trend where organic materials were used compared to inorganic fertilizer treatment except rice straw. Overall PM+IPNS treatment produced higher grain yield both in T. Aman (4.07 t/ha) and Boro season (5.44 t/ha).

Project Information

1. Sub-Project title: Carbon Sequestration in Soils of Bangladesh: BRRI Component

2. a) Principal Investigator: Dr. Pranesh Kumar Saha, Chief Scientific Officer and Head

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4. Duration of the sub-project: April 18, 2010 to June 30, 2014

5. Date of Approval: April 18, 2010

6. Financial Progress:

Total approved Budget	: Taka 66,46,221/-
Total fund received	: Taka 63,30,057/-
Total fund Spent	: Taka 63,04,482/-
Unspent/Balance of fund	: Taka 25,575/-

7. Justification of undertaking the sub-project:

World soils and terrestrial ecosystems have been a source of atmospheric abundance of CO_2 (Lal, 2008). Therefore, soil is important to account for carbon stocks under different crop and land management practices. Soils of Bangladesh have low reserves of carbon and plant nutrients due to increasing cropping intensity, higher rates of decomposition of organic matter under the prevailing hot and humid climate, use of lesser quantity of organic manure, little or no use of green manuring practices. The highest depletion of soil carbon has been reported in soils of Meghna river floodplain (35%), followed by Madhupur tracts (29%), Brahmaputra floodplain (21%), Old Himalayan piedmontplain (18%) and Gangetic floodplain (15%) (BARC, 2005). Carbon stocks are not only critical for the soil to perform its productivity and environmental functions but also play an important role in the global C cycle. The sequestration of atmospheric C in the soil and biomass reduces greenhouse effect. Carbon sequestration is essential to improve soil quality, increase agronomic productivity and use efficiency of inputs like fertilizers and water thus helps maintain or restore the capacity of soil to perform its production and

environmental functions on a sustainable basis. Therefore, there is a great demand of research on atmospheric C sequestration into the soils.

A soil plays an important role in the global carbon budget and is important to account for soil carbon stocks in different soils under different land use regimes (Mikhailova and Post, 2006). The global concerns about the effects of climate change have generated urgent research avenues on both soil organic and inorganic C stocks. Soil structure is an important property that controls soil organic carbon (SOC) content. Cultivation affects soil structure through destruction of soil aggregates. Crop and soil management practices can effect the formation and the stabilization of soil aggregate through changes in SOC levels and soil microclimate (Maysoon et al., 2007). Reduction of tillage on arable land under different cropping systems and seasons reduces mineralization of SOC thus C stocks can be increased over time, which needs intensive field research.

There is a critical need for best management practices to sequester carbon in soils (Russell et al., 2005). It is predicted that the crop production of Bangladesh would be tremendously vulnerable to climate change. Therefore, the food security will be at risk. Some agronomic manipulation in the cropping systems and their management practices would be needed to address this issue. Selection of current and alternative cropping systems with the understanding of the dynamics of carbon stock in soils as influenced by management practices is necessary for maintaining soil carbon at a level critical for maintaining soil health and also for restraining global warming. Management practices like diversified cropping systems, application of wastes/compost and tillage operation coupled with cropping systems and optimum fertilization are believed to offer the high potential to increase carbon level in soils. Carbon sequestration reflects the long-term balance between additions of organic C from different sources and its losses from soil. Following the adoption of large-scale intensive cropping, with the introduction of modern varieties and increased use of chemical fertilizers, this long-term balance was modified. Intensive cropping encourages oxidative losses of C due to continued soil disturbance, while it also leads to a large-scale addition of C to the soil through crop residues. This may cause either a net buildup or a net depletion of soil carbon stock (Cole et al., 1993; Kong et al., 2005). However, information on soil carbon balance in the major cropping patterns under different AEZs of Bangladesh is not well documented, which needs to be estimated.

8. Sub-project objective(s):

1. To quantify the present status of carbon in soils in thirty agro-ecological zones of Bangladesh

2. To determine the effects of different cropping systems and management practices on soil carbon stocks

3. To evaluate the degree of carbon sequestration using integrated nutrient management

4. To establish the relationship among cropping systems and management practices with the soil carbon stock and systems productivity.

9. Methodology followed in conducting research/investigation:

The following approaches and methodologies were adopted to fulfill the objectives of the proposed research project.

Assessment of existing carbon stock in soils of 10 AEZs in Bangladesh

The soil samples were collected from ten AEZs: AEZ 1. Old Himalayan Piedmont Plain, AEZ. 2. Active Tista Flood Plain, AEZ. 3. Tista Meander Flood Plain, AEZ 4. Karatoya-Bangali Floodplain, AEZ 5. Lower Atrai Basin, AEZ 6. Lower Purnabhaba Floodplain, AEZ 7. Active Brahmaputra and Jamuna Floodplain, AEZ 8. Young Brahmaputra and Jamuna Floodplain, AEZ 9. Old Brahmaputra Floodplain and AEZ 10. Active Ganges Floodplain. Two upazilas of a district under each AEZ were selected for soil collection. The upazilas were Haripur & Ranisonkail of Thakurgaon district under AEZ-1, Patgram and Hatibandha of Lalmonirhat district under AEZ-2, Rangpur Sadar and Pirgachha of Rangpur district under AEZ-3, Sajahanpur and Dhunat of Bogra district under AEZ-4, Singra of Natore district and Atrai of Naogaon district under AEZ-5, Gomostapur of Nawabganj district under AEZ-6, Gaibandha sadar and Fulchori of Gaibandha district under AEZ-7, Tangail sadar and Bhuapur of Tangail district under AEZ-8, Sarishabari and Jamalpur Sadar of Jamalpur district under AEZ-9 and Nawabganj sadar and Shibganj of Nawabganj district under AEZ-10. From one upazila, three villages were considered for soil sample collection. Soil samples were collected based on land types and major cropping pattern in each of the ten AEZs. Global Positioning System (GPS) reading was taken in each and every location of sample collection. Major cropping patterns were rice- fallow -rice, rice-non rice-fallow and fallow-fallow-rice. A total of 2188 soil samples were collected from ten AEZs following the described sample collection protocol: two upazilas/AEZ, three villages/upazila, 10 sampling spots/village, 4 samples/spot. From each sampling spot soil samples were collected considering 4 soil

depths (0-5, 5-10, 10-15 and 15-20 cm). Soil samples were analyzed for organic carbon by wet oxidation method (Walkley and Black, 1934). Bulk density (g/cm^3) was determined by core sampler method (Blake and Hartge, 1986) considering 4 soil depths (0-5, 5-10, 10-15 and 15-20 cm) under different land types. The Carbon stock (t/ha) in soils were calculated by using the following equation (Komatsuzaki and Syuaib, 2009):

Carbon stock (t/ha) = organic carbon content (%) x bulk density (g/cm^3) x soil depth (cm)

Carbon accumulation and its mineralization in soils under aerobic and anaerobic condition without crop (laboratory)

This experiment has been set up in the laboratory of Soil Science Division, BRRI on September 20, 2012 at room temperature (18^0C to 34^0C) for 129 days. The bulk soil sample was collected from AEZ 1 (GPS: 25^0 56.855N; 088^0 09.887E). After collection, the soils were air dried, ground and sieved with 5 mm sieve. A composite soil sample was analyzed for organic carbon, total N, available P and exchangeable K. Results are shown in Table 1. In this experiment plastic jars (1100 ml air tight pot) were used. Respective jar was filled with 100 g of bulk soils. Different organic materials such as rice straw (RS), rice root (RR), cow dung (CD) and poultry manure (PM) were analyzed (Table 2) and incorporated in the jar @ 5 t C/ha (0.25 g C/100 g soil or without soil) basis for each organic material.

One jar was without organic materials and soil i.e. control blank. Then the soils were prepared with organic materials and two moisture regimes e.g. moist and flooding condition. The experiment was laid out in RCBD factorial with two replications. Organic materials were considered as factor A and moisture regimes were factor B.

Table 1. Initial Soil properties of the pot experiment

Parameters	Value (n=5)	STDEV (n=5)
pH	4.78	±0.04
OC (%)	1.1	±0.05
Total N (%)	0.11	±0.02
Available P (mg/kg)	9.18	±0.18
Exch. K (Cmol/kg soil)	0.07	±0.01

Table 2. Nutrient contents of organic matters applied in the pot experiment

Source (s)	OC (%) n=3	Total N (%) n=3	Total P (%) n=3	Total K (%) n=3
Rice Straw	42	0.5	0.28	0.79
Rice Root	25	0.79	0.60	0.56
Cow dung	20	0.85	0.50	0.52
Poultry manure	20	2.28	1.03	1.20

The treatment combinations were as follows:

Factor A:

T_1= Control (Soil)	T_6= Rice Straw
T_2= Soil+Rice Straw	T_7= Rice Root
T_3= Soil+Rice Root	T_8= Cow dung
T_4= Soil+ Cow dung	T_9= Poultry manure
T_5= Soil+Poultry manure	

Factor B:

i) Moist condition (around field capacity) of tested materials and

ii) Continuous flooding (1 cm water level)

The total no. of jars were 40 ((9x2x2) +4). Each jar contained a 75 ml vial containing 25 ml of distilled water, and 20 ml of 1N NaOH. The jars were air tight and incubated at room temperature (18^0C to 34^0C) for 129 days. The CO_2 evolved by microbial respiration was measured twice a week for first two months and the rest two months once a week. The CO_2 was determined by titration of the residual NaOH with 0.5N HCl using one drop of 1% phenolphthalein indicator and 3 ml of 1N $BaCl_2$ solutions. The CO_2 was calculated.

Calculation of C balances:

Carbon balance = Input – Output

Input = Inherent soil carbon+ added carbon using residues and manure

Output = Carbon emission + residual carbon in soil

Carbon accumulation and its mineralization in soils under aerobic and anaerobic condition with rice

This experiment was conducted in the net house of Soil Science Division, Bangladesh Rice Research Institute (BRRI), Gazipur during 22 March 2011 to 28 September 2011. The bulk soil sample was collected from AEZ 1: Old Himalayan Piedmont Plain (GPS: 25^0 56.855N; 088^0 09.887E). The soil texture of the collected soil is sandy loam having strongly acidic in nature (pH = 4.78). Soil organic carbon content of the soil is 1% (medium). After collection, the soils were air dried, ground and sieved with 5 mm sieve. In this experiment plastic pots with 27 cm x 28 cm sized were used. Each pot was filled with 10 kg of bulk soils. There were four different organic residues (Rice straw, rice roots, poultry manure and cow dung), five carbon rates (0, 0.5, 1.0, 1.5 and 2.0 t ha^{-1}) and two moisture regime (moist condition and continuous standing water) as treatments. Rice straw, rice root, cow dung and poultry manure (having the carbon content 40%,

24%, 28% and 23%, respectively) were incorporated in the pot soils @ 0.0, 0.5, 1.0, 1.5 & 2.0 t C/ha basis for each organic material. Then the soils were prepared on 28 March 2011 with two moisture regimes e.g. Alternate Wetting and Drying (AWD) and Continuous standing water (CSW) condition for transplanting. The experiment was laid out in RCBD factorial with three replications.

After preparation of pot soils, 26 days old seedlings of MV rice BR 22 were transplanted. Each pot contained two hills followed by 2 seedlings per hill. Soil samples were collected on 30days interval up to 180 DAT for the measurement of soil organic carbon and soil pH. Soil pH was determined by glass electrode pH meter method with soil-water ratio 1:2.5 (McLean, 1982) and soil organic carbon content was determined by wet oxidation method (Walkley and Black, 1934).

Statistical analysis was done following the CropStat version 7.0 software.

Field experimentation:

Different field experiments were conducted using integrated nutrient management (organic/inorganic sources of nutrients), and tillage operation (minimum/traditional tillage) as experimental factors.

Carbon sequestration in soils under different tillage and rice straw management

This experiment was conducted during the period T. Aman 2010-T. Aman 2013 at the BRRI H/Q Farm, Gazipur (AEZ-28, Modhupur Tract, medium highland). The soil of the experimental field was clay-loam in texture and slightly acidic (pH-6.46). The content of soil organic C, total N, available P, exchangeable K and available Zn (DTPA) of the soil were 1.57%, 0.10%, 7.5 mg/kg, 0.13 Cmol/kg soil and 1.11 mg/kg soil respectively. The following treatments were used in this experiment:

Factor A: Tillage method

1. Minimum tillage (MT)
2. Traditional tillage (TT)

Factor B: Straw management (rice straw @ 5 t/ha)

1. Control – no rice straw (NRS)
2. Rice straw – soil incorporation (IRS)
3. Rice straw – surface mulch (SRS)

The experiment was laid out in a RCB (two-factorial) design with three replications. Each plot received a fertilizer dose of NPK @ 75, 10 and 75 kg/ha, respectively in T.

Aman season and @ 150, 10 and 75 kg/ha, respectively in Boro season. BRRI dhan31 in T. Aman season and BRRI dhan29 in Boro season were used as test variety. At maturity grain, straw and root dry matter yield was recorded. The crop was harvested from 5 m^2 areas at the central part of each plot and 16 hills were collected for straw and root yield. The grain yield was recorded at 14% moisture content whereas straw and root yield as oven dry basis.

CO_2 emission was measured by the following standard method (Jain *et. al.*, 2003) in both T. Aman and Boro seasons. Reading was taken by every 7 days interval and it was continued throughout the crop growing season. A CO_2 trap was prepared using 80 ml of 2 N NaOH into a plastic bottle and placed it in the plots under different treatments. Each trap was covered with a plastic bucket, which was inserted into soft mud to protect entrance of air CO_2 into bucket. After 7 days of exposure the alkali bottle was removed from the plot covering with screw cap and then it was titrated against 0.5 N hydrochloric acid. An empty bucket was used as a control for this experiment without soil but the alkali of the same strength. The alkali solutions from the control and those exposed to soil were titrated to determine the quantity of alkali that has not reacted with CO_2. For this purpose, 2 ml saturated $BaCl_2$ was added to the NaOH solution to precipitate the carbonate as insoluble $BaCO_3$. From 80 ml of alkali solution exactly 10 ml was titrated adding 2 ml saturated $BaCl_2$ and few drops of 1% phenolphthalein indicator against 0.5N HCl. The acid was added slowly to avoid contact with possible dissolution of the precipitated $BaCO_3$. The volume of acid which was needed to titrate the alkali was noted. The amount of CO_2 evolved from the soil during exposure to alkali was calculated using the formula: Milligrams of CO_2 = (B-V) N E

Where, B = volume (ml) of acid needed to titrate NaOH in the jars from the control cylinders, V = volume (ml) of acid needed to titrate the NaOH in the beakers exposed to the soil atmosphere, N = normality of the acid and E = equivalent weight. To express the data in terms of carbon, E = 6d; to express it as CO_2, E = 22. Data were expressed as CO_2 kg/ha/day per crop growing seasons.

After the harvesting of fifth crop, the soil samples were collected for determination of organic C.

Statistical analysis was done following the Crop Stat version 7.0 software.

Effect of different organic manures/residues and fertilizer management on carbon sequestration under rice–rice pattern

This experiment was initiated in T.Aman Season 2010 at the BRRI H/Q Farm, Gazipur (AEZ-28, Modhupur Tract, Medium High Land). The soil of the experiment field was clay-loam in texture and neutral in nature (pH-6.7). The content of soil organic C, total N, available P, exchangeable K and available Zn (DTPA extracted) of the soil were 1.50 %, 0.18%, 7.2 mg/kg, 0.13 Cmol/kg soil and 0.64 mg/kg soil respectively. The following treatments were used in this experiment: T_1= Absolute Control, T_2= Cow dung + IPNS based chemical fertilizer (CD+IPNS), T_3= Poultry manure + IPNS based chemical fertilizer (PM+IPNS), T_4= Rice straw + IPNS based chemical fertilizer (RS+IPNS) and T_5=Soil test based (STB) chemical fertilizer. The experiment was laid out in a RCB design with four replications. Organic materials were used at the rate of 2 ton C/ha. STB dose was NPK @ 75, 10 and 75 kg/ha, respectively in T. Aman season and 162, 24 and 75 kg/ha respectively in Boro season. BRRI dhan31 in T. Aman season and BRRI dhan29 in Boro season were used as test variety. All intercultural operations were done as per requirement. At maturity stage, grain, straw and root yield was recorded. At maturity stage, the crop was harvested from 5 m^2 areas at the central part of each plot and 16 hills were collected for straw and root yield. The grain yield was recorded at 14% moisture content and straw and root yield as oven dry basis.

CO_2 emission was measured by the following standard method (Jain *et. al.*, 2003) in both T. Aman and Boro seasons (described as previous experiment, page No. 7).

After the harvesting of 5^{th} crop, the soil samples were collected for determination of organic C, total N, available P, exchangeable K and available Zn (DTPA extracted) following the standard procedure.

Calculation of C balances:

Carbon balance = Input – Output

Input = Inherent soil carbon+ added carbon using residues and manures

Output = Carbon (emission) + residual carbon in soil

Statistical analysis was done following the Crop Stat version 7.0 software.

Methods of soil and plant analysis:

Soil pH was measured by glass electrode pH meter method using soil water ratio 1:2.5 (McLean, 1982). Organic carbon content of soil samples was estimated by wet oxidation

method (Walkley and Black, 1934). The total N of soil sample was determined following micro-Kjeldahl method (Bremner and Mulvaney, 1982) Available soil phosphorus was measured by modified Olsen's method (Olsen and Sommers, 1982) and available Zn was determined by DTPA extraction method. Exchangeable K of soils was determined by flame photometer on the neutral ammonium acetate extract (Barker and Surh, 1982).

10. Results and discussion:

Carbon sequestration is essentially the process of transforming C from the air (CO_2) in to stored soil C (Rice and Mc Vay, 2002). Some agronomic manipulation in the cropping systems and their management practices would be needed to address this issue. Carbon sequestration reflects the long-term balance between additions of organic C from different sources and its losses from soil. Following the adoption of large-scale intensive cropping, with the introduction of modern varieties and increased use of chemical fertilizers, this long-term balance was modified. Intensive cropping encourages oxidative losses of C due to continued soil disturbance, while it also leads to a large-scale addition of C to the soil through crop residues. This may cause either a net buildup or a net depletion of soil carbon stock (Cole et al., 1993; Kong et al., 2005). However, information on soil carbon balance in the major cropping patterns under different AEZs of Bangladesh is not well documented, which needs to be estimated. As a source of nutrients for growing crops the soil organic carbon (SOC) pool is a mean of production in subsistence farming systems. In agricultural fallow land of tropical countries like Bangladesh the fate of SOC may differ from continuous crop lands. It is reported that the content of SOC in rice-rice cropping pattern is more than that of upland crops. Alternate Wetting and Drying (AWD) may change the SOC. The mineralization rate depends on the nature of organic matter (OM), temperature, moisture etc. The mineralization rates of different organic matters are not so well known. So this is very much needed to determine the CO_2 emission rate of some OM and also to determine the changes of SOC under AWD and continuous flooding condition with rice crop. Soil structure is an important property that controls soil organic carbon (SOC) content. Cultivation affects soil structure through destruction of soil aggregates. Crop and soil management practices can effect the formation and the stabilization of soil aggregate through changes in SOC levels and soil microclimate (Maysoon et al., 2007). Reduction of tillage on arable land under different cropping systems and seasons reduces mineralization of SOC thus C stocks can be increased over time, which needs intensive field research. The level of soil

organic carbon which is influenced by tillage operations, rice straw management and fertility levels under irrigated Rice-Rice cropping pattern and the rates of carbon dioxide emission from rice soils influenced by those managements should be studied. Long-term carbon storage data in soils is important at national level to understand contribution of a country to global warming. To enhance soil organic C for increasing soil quality and agronomic productivity application of crop residues, mulch and other bio solids including compost and manure is necessary. Changing of soil organic C due to the application of various organic materials at different fertility levels and the rates of carbon dioxide emission from rice soils influenced by that management needed to quantify. On the above discussions the following experiments were conducted.

Assessment of existing carbon stock in soils of 10 AEZ in Bangladesh

Types of lands and their extent under different AEZs are shown in the Table 3.

Table 3. : Land type distribution among different AEZs

AEZ	Area (ha)					Percentage				
	HL	MHL	MLL	LL	VLL	HL	MHL	MLL	LL	VLL
1	230929	135372	3982	--	--	58	34	1	--	--
2	1673	60224	--	--	--	2	72	--	--	--
3	331,381	482,870	37,872	9,468	--	35	51	4	1	--
4	59,146	113,150	36,002	2,572	--	23	44	14	1	--
5	1702	6808	17872	55318	---	2	8	21	65	---
6	---	---	1290	7740	---	---	---	10	60	---
7	15950	118030	63800	25520	--	5	37	20	8	--
8	10662	24878	11254	5331	--	18	42	19	9	--
9	202,450	253,063	144,607	50,61 3	--	28	35	20	7	--
10	4014	11038	6020	1338	---	12	33	18	4	---

AEZ 1: Old Himalayan Piedmont Plain

AEZ 1 is located at most of Panchagarh and Thakurgaon districts and north-western parts of Dinajpur district. Major land types are Highland (58%), Medium Highland (34%), Medium Lowland (1%) and Homestead + Water (7%) (Table 3). The soil texture is sandy-loam. The SOC content (%) in highland was low (1.04% to 0.74%), in medium highland it was medium to low (1.41% to 0.90%) and that in medium lowland it was high to medium (2.30% to 1.87%), as per SOC ranking outlined in FRG-2005 (BARC, 2005). It was observed that the SOC content (%) decreased with increasing of soil depths

irrespective of land types (Table 4). However, the SOC content (%) in medium lowland was higher than that in high and medium highlands. The average SOC stocks of the land types were 7.13 to 5.50, 8.79 to 7.51 and 15.88 to 13.06 t/ha respectively. The highest SOC stock was observed in medium lowland and the lowest in highland. It appeared that the SOC stock increased up to 10 cm soil depth in highland and medium lowland and then decreased with the increase of soil depth while in medium highland the trend was different. The highest SOC stock (8.79 t/ha) was found in 0 to 5 cm depth and the lowest (7.51 t/ha) in 15 to 20 cm depth (Table 5). Over the 0-20 cm soil depth the highest amount of SOC content (2.10%) was found in medium lowland and the lowest amount (0.89%) in highland (Table 6). Similar trend was observed in case of SOC stock. It varied from 14.19 (t/ha) in medium lowland to 6.46 (t/ha) in highland. Bulk density of medium highland varied from 1.26 to 1.67 g/cc, in highland from 1.33 to 1.55 g/cc and for medium lowland it was 1.13 to 1.44 g/cc (Table 7). Medium highlands were more compact at 10-15 cm and 15-20 cm soil layer than other land types. With the increase of soil depth bulk density increased more distinctly in medium highland than in highland and medium lowland. The lowest bulk density was found in medium lowland because of higher moisture content and flocculent soft layer in the top soils of medium lowland which contributed to less dry mass compared to medium highland and highland.

AEZ 2: Active Tista Floodplain

This AEZ occupies narrow belts within and adjoining the channels rivers in Nilphamari, Rangpur, Lalmonirhat, Kurigram and Gaibandha district and the total area is 836 km^2 (83644 ha). Major land types are Highland (2%), Medium Highland (72%) and Homestead + Water (26%) (Table 3). The soil texture is sandy-loam. The SOC content (%) in highland was medium to very low (1.18% to 0.46%) and in medium highland it was low to very low (0.90% to 0.52%), as per SOC ranking outlined in FRG-2005 (BARC, 2005) (Table 4). The average SOC stocks of the land types were 7.66 to 3.36 and 4.49 to 3.25 t/ha respectively. The highest SOC stock was observed in highland and the lowest in medium highland. It appeared that the SOC stock decreased gradually with the increase of soil depth irrespective of land types (Table 5). Over the 0-20 cm soil depth the highest amount of SOC content (0.79%) was found in highland and the lowest amount (0.70%) in medium highland (Table 6). Similar trend was observed in case of SOC stock. It varied from 5.51 (t/ha) in highland to 3.98 (t/ha) in medium highland. Bulk density of highland varied from 1.28 to 1.42 g/cc and in medium highland from 1.00 to

1.17 g/cc (Table 7). With the increase of soil depth bulk density increased. The lowest bulk density was found in medium highland.

AEZ. 3. Tista Meander Floodplain

AEZ 3 is located at most of greater Rangpur, eastern part of Panchagarh and Dinajpur, Northern Bogra and part of Joypurhat, Naogaon and Rajshahi districts. Major land types are Highland (35%), Medium Highland (51%), Medium Lowland (4%), Lowland (1%) and Homestead + Water (7%) (Table 3). The soil texture is loamy. The SOC content (%) in highland was low to very low (0.70% to 0.36%), in medium highland it was medium to low (1.20% to 0.57%) and in lowland was medium to low (1.39% to 0.73%), as per SOC ranking outlined in FRG-2005 (BARC, 2005) (Table 4). The average SOC stocks of the land types viz. highland, medium highland and lowland were 4.35 to 2.51, 7.11 to 4.44 and 7.21 to 5.31 t/ha respectively. The highest SOC stock was observed in lowland and the lowest was in highland. It appeared that the SOC stock increased up to 10 cm soil depth in medium highland and lowland and then decreased with the increase of soil depth while in highland the trend was different. The highest SOC stock (4.35 t/ha) was found in 0 to 5 cm depth and the lowest (2.51 t/ha) was in 15 to 20 cm depth (Table 5).

Table 6 indicates that the highest amount of SOC content (1.05%) was in lowland and the lowest amount (0.50%) in highland over the 0 - 20 cm soil depth. Similar trend was noticed in case of SOC stock. It ranged from 6.45 (t/ha) in lowland to 3.39 (t/ha) in highland. Bulk density of medium highland varied from 1.12 to 1.57 g/cc, in highland from 1.23 to 1.48 g/cc and for lowland it was 1.01 to 1.46 g/cc (Table 7). Medium highlands were more compact at 10-15 cm and 15-20 cm soil layer than other land types. With the increase of soil depth bulk density increased more distinctly in high and medium highlands than in lowland. The lowest bulk density was found in lowland because of higher moisture content and flocculent soft layer in the top soils of lowland which contributed to less dry mass compared to medium highland and highland.

AEZ 4: Karatoya-Bangali Floodplain

AEZ 4 is located at eastern half of Bogra district and most of Sirajgonj district. Major land types are Highland (23%), Medium Highland (44%), Medium Lowland (14%), lowland (1%) and Homestead + Water (14%) (Table 3). The soil texture is silty loam and silty clay loam. The SOC content (%) in highland was medium to very low (1.12% to 0.39%), in medium highland it was medium to very low (1.08% to 0.26%) and in lowland was low to very low (0.96% to 0.35%), as per SOC ranking outlined in FRG-

2005 (BARC, 2005). It was observed that the SOC content (%) decreased with increasing of soil depths irrespective of land types (Table 4). The average SOC stocks of the land types viz. highland, medium highland and lowland were 6.00 to 3.03, 8.10 to 2.08 and 7.24 to 2.66 t/ha respectively (Table 5). At 0-5 cm layer, the highest SOC stock was observed in medium highland and the lowest in highland. Over the 0-20 cm soil depth the highest amount of SOC content (0.69%) was found in highland and the lowest amount (0.61%) in medium highland (Table 6) and the trend was different in case of SOC stock. It ranged from 4.67 (t/ha) in lowland to 4.58 (t/ha) in medium highland and highlands. Bulk density of highland varied from 1.10 to 1.65 g/cc, in medium highland from 1.46 to1.58 g/cc and for lowland it was 1.49 to 1.61 g/cc (Table 7). In all land types at 10-15 cm and 15-20 cm soil layer bulk density was higher than that of 0-5 cm and 5-10 cm layer. It indicates that lower soil layers were comparatively compact than upper layer.

AEZ 5: Lower Atrai Basin

This AEZ is located at Naogaon and Natore districts but small areas extend into Rajshahi, Bogra and Sirajgonj district. Major land types are Highland (2%), Medium Highland (8%), Medium Lowland (21%), lowland (65%) and Homestead + Water (4%) (Table 3). The soil texture is clay. The SOC content (%) in highland was low to very low (0.68% to 0.27%), in medium highland it was low to very low (0.78% to 0.26%), in medium lowland it was low to very low (0.78% to 0.33%) and in lowland it was low to very low (0.93% to 0.50%), as per SOC ranking outlined in FRG-2005 (BARC, 2005). It was observed that the SOC content (%) decreased with increasing of soil depths irrespective of land types (Table 4). The average SOC stocks of the land types viz. highland, medium highland, medium lowland and lowland were 3.26 to 1.95, 5.42 to 2.09, 4.68 to 2.46 and 6.09 to 4.01 t/ha respectively (Table 5). Over the 0-20 cm soil depth the highest amount of SOC content (0.71%) was found in lowland and the lowest amount (0.45%) in highland (Table 6). However, the SOC content (%) in lowland was higher than that in highland, medium highland and medium lowland. and the trend was similar in case of SOC stock. It ranged from 5.22 (t/ha) in lowland to 2.64 (t/ha) in highland. Bulk density of highland varied from 0.81 to 1.43 g/cc, in medium highland from 1.38 to 1.63 g/cc, in medium lowland from 1.19 to 1.50 g/cc and for lowland it was 1.32 to 1.60 g/cc (Table 7). With the increase of soil depth bulk density increased. The lowest bulk density was found in highland.

AEZ 6: Lower Purnabhaba Floodplain

AEZ 6 is located at extreme western part of Naogaon district and the extreme northern part of Nawabganj district. Major land types are Medium Lowland (10%), lowland (60%) and Homestead + Water (30%) (Table 3). The soil texture is clay. The SOC content (%) in medium lowland was medium to very low (1.30% to 0.50%) and in lowland it was medium to low (1.39% to 0.77%), as per SOC ranking outlined in FRG-2005 (BARC, 2005). However, the SOC content (%) in lowland was higher than that in medium lowland (Table 4). The average SOC stocks of the land types viz. medium lowland and lowland were 6.87 to 3.52 and 5.80 to 4.46 t/ha respectively (Table 5). It appeared that the SOC stock decreased gradually with the increase of soil depth irrespective of land types. Over the 0-20 cm soil depth the highest amount of SOC content (1.09 %) was found in lowland and the lowest amount (1.88%) in medium lowland (Table 6) and the trend was different in case of SOC stock. It ranged from 5.39 (t/ha) in medium lowland to 5.31 (t/ha) in lowland. Bulk density of medium lowland varied from 1.06 to 1.42 g/cc and in lowland from 0.84 to 1.16 g/cc (Table 7). With the increase of soil depth bulk density increased. The lowest bulk density was found in lowland.

AEZ 7: Active Brahmaputra and Jamuna Floodplain

AEZ 7 is located at most of eastern parts of Kurigram, Gaibandha, Bogra, Sirajganj, Pabna and Manikganj districts. Minor areas also occur in Dhaka, Munshiganj, Narayanganj and Chandpur districts. Major land types are Highland (5%), Medium Highland (37%), Medium Lowland (20%), lowland (8%) and Homestead + Water (30%) (Table 3). The soil texture is sandy-loam. The SOC content (%) in highland was medium to very low (1.33% to 0.44), in medium highland it was medium to very low (1.42% to 0.42%) and in lowland it was medium to low (1.72% to 0.69%), as per organic carbon ranking (BARC, 2005). The average SOC stocks of the land types viz. highland, medium highland and lowland were 7.47 to 3.22, 7.86 to 3.40 and 8.88 to 5.20 t/ha respectively (Table 5). It appeared that the SOC stock decreased gradually with the increase of soil depth irrespective of land types. Over the 0-20 cm soil depth the highest amount of SOC content (1.17%) was found in lowland and the lowest amount (0.80%) in highland (Table 6) and the trend was similar in case of SOC stock. It ranged from 7.36 (t/ha) in lowland to 5.32 (t/ha) in highland. Bulk density of highland varied from 1.12 to 1.61 g/cc, in medium highland from 1.11 to 1.64 g/cc and for lowland it was 1.03 to 1.51 g/cc (Table 7). In high and medium highlands bulk density gradually increased up to 10-15 cm layer

and then decreased but in lowland it increased up to 15-20 cm layer. The highest bulk density was found in medium highland.

AEZ 8: Young Brahmaputra and Jamuna Floodplain

Major land types are Highland (18%), Medium Highland (42%), Medium Lowland (19%), Lowland (9%) and Homestead + Water (12%) (Table 3). The soil texture is sandy/silty. The SOC content (%) in highland was medium to very low (1.26% to 0.40), in medium highland it was medium to very low (1.50% to 0.45%) and in lowland it was high to low (2.57% to 0.94%), as per organic carbon ranking (BARC, 2005). The average SOC stocks of the land types viz. highland, medium highland and lowland were 6.15 to 2.99, 8.01 to 3.39 and 9.31 to 6.27 t/ha respectively (Table 5). It appeared that the SOC stock decreased gradually with the increase of soil depth irrespective of land types. Over the 0-20 cm soil depth the highest amount of SOC content (1.71%) was found in lowland and the lowest amount (0.77%) in highland (Table 6) and the trend was similar in case of SOC stock. It ranged from 8.11 (t/ha) in lowland to 4.43 (t/ha) in highland. Bulk density of highland varied from 0.99 to 1.45 g/cc, in medium highland from 1.12 to 1.53 g/cc and for lowland it was 0.77 to 1.36 g/cc (Table 7). With the increase of soil depth bulk density increased irrespective of land types. The highest bulk density was found in medium highland and the lowest was in lowland.

AEZ 9: Old Brahmaputra Floodplain

Major land types are Highland (28%), Medium Highland (35%), Medium Lowland (20%), Lowland (7%) and Homestead + Water (10%) (Table3). The soil texture is silty loam. The SOC content (%) in highland was medium to very low (1.37% to 0.40%), in medium highland it was medium to very low (1.59% to 0.45%) and in lowland it was high to low (2.30% to 0.90%), as per SOC ranking outlined in FRG-2005 (BARC, 2005). The average SOC stocks of the land types viz. highland, medium highland and lowland were 8.46 to 3.29, 10.67 to 3.41 and 14.07 to 7.22 t/ha respectively (Table 5). The highest SOC stock (14.07 t/ha) was found in 5 to 10 cm depth in lowland and the lowest (3.29 t/ha) in 15 to 20 cm depth in highland. From the Table 6, it was shown that the highest amount of SOC content (1.64%) in lowland and the lowest amount (0.82%) in highland over the 0 - 20 cm soil depth. Similar trend was also observed in case of SOC stock, it ranged from 11.71 (t/ha) in lowland to 5.65 (t/ha) in highland. Bulk density of medium highland varied from 1.35 to 1.58 g/cc, in highland from 1.23 to 1.62 g/cc and for lowland it was 1.20 to 1.63 g/cc (Table 7). Medium highlands were more compact at

0-5 cm and 5-10 cm soil layer than other land types. With the increase of soil depth bulk density increased more distinctly in medium highland and lowland than in highland up to 10-15 cm and then decreased. The lowest bulk density was found in lowland because of higher moisture content and flocculent soft layer in the top soils of lowland which contributed to less dry mass compared to medium highland and highland.

AEZ 10: Active Ganges Floodplain

AEZ 10 extends along the Ganges and lower Meghna river channels from the Indian border, Nawabganj and Rajshahi district to the mouth of Meghna estuary in Lakshmipur and Barisal district. Major land types are Highland (12%), Medium Highland (33%), Medium Lowland (18%), Lowland (4%) and Homestead + Water (33%) (Table3). The soil texture is loamy. The SOC content (%) in medium highland was low to very low (0.92% to 0.51%) and in lowland it was medium to low (1.24% to 0.84%), as per SOC ranking outlined in FRG-2005 (BARC, 2005). The average SOC stocks of the land types viz. medium highland and lowland were 6.18 to 3.79 and 7.22 to 5.37 t/ha respectively (Table 5). It appeared that the SOC stock decreased gradually with the increase of soil depth irrespective of land types. From the Table 6, it was shown that the highest amount of SOC content (1.05%) in lowland and the lowest amount (0.72%) in medium highland over the 0 - 20 cm soil depth. Similar trend was also observed in case of SOC stock, it ranged from 6.41 (t/ha) in lowland to 5.03 (t/ha) in medium highland. Bulk density of medium highland varied from 1.33 to 1.48 g/cc and for lowland it was 1.20 to 1.31 g/cc (Table 7). With the increase of soil depth bulk density increased irrespective of land types. The lowest bulk density was found in lowland because of higher moisture content and flocculent soft layer in the top soils due to high organic matter of lowland which contributed to less dry mass compared to medium highland.

In low land areas only Boro rice was grown and in high and medium highlands T. Aman and Rabi crops were grown. It indicates that tillage operation was more in high and medium highlands and less in lowland. It is recognized that organic matter decomposition is faster under frequent tillage operations (Gebhart et al., 1994) and further in lowland top soils with organic debris are deposited through surface run off and low land soils remain submergence for a longer period. Under the above mentioned situation the OM decomposition is slower in low laying areas.

Table 4. : Soil organic carbon content (%) at different depth of soils in different AEZs of Bangladesh

AEZ	Land type/depth (cm)															
	HL				MHL				MLL				LL			
	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20
1	1.04±0.08	0.95±0.09	0.81±0.09	0.74±0.09	1.41±0.08	1.29±0.06	1.07±0.08	0.90±0.10	2.30±0.20	2.20±0.19	2.02±0.18	1.87±0.19				
2	1.18±0.04	0.90±0.05	0.64±0.04	0.46±0.03	0.90±0.06	0.75±0.05	0.63±0.05	0.52±0.05								
3	0.70±0.05	0.52±0.05	0.44±0.05	0.36±0.05	1.20±0.08	1.02±0.09	0.83±0.09	0.57±0.10					1.39±0.17	1.18±0.16	0.89±0.14	0.73±0.13
4	1.12±0.06	0.75±0.06	0.48±0.05	0.39±0.05	1.08±0.05	0.74±0.05	0.35±0.03	0.26±0.02					0.96±0.11	0.68±0.08	0.48±0.06	0.35±0.04
5	0.68±0.04	0.47±0.05	0.37±0.05	0.27±0.03	0.78±0.06	0.52±0.05	0.31±0.03	0.26±0.02	0.78±0.04	0.66±0.03	0.38±0.01	0.33±0.01	0.93±0.08	0.79±0.08	0.63±0.09	0.50±0.08
6	---	---	---	---	---	---	---	---	1.30±0.07	1.04±0.06	0.70±0.05	0.50±0.05	1.39±0.09	1.17±0.08	1.01±0.06	0.77±0.06
7	1.33±0.05	0.93±0.07	0.52±0.02	0.44±0.02	1.42±0.08	1.00±0.07	0.59±0.04	0.42±0.04					1.72±0.11	1.33±0.11	0.94±0.09	0.69±0.07
8	1.26±0.07	0.91±0.06	0.52±0.03	0.40±0.02	1.50±0.08	1.15±0.10	0.60±0.04	0.45±0.03					2.57±0.14	2.00±0.14	1.32±0.10	0.94±0.06
9	1.37±0.07	1.01±0.07	0.50±0.03	0.40±0.03	1.59±0.06	1.15±0.07	0.65±0.5	0.45±0.04					2.30±0.11	1.94±0.10	1.43±0.13	0.90±0.11
10*	---	---	---	---	0.92±0.09	0.78±0.08	0.66±0.08	0.51±0.07	---	---	---	---	1.24±0.23	1.12±0.22	1.00±0.22	0.84±0.20

*Note: In AEZ 10 there are four land types viz. HL, MHL, MLL & LL. But the soil samples were collected only from MHL and LL.

Table 5. : Organic carbon stock (t/ha) at different depth of soils in different AEZs of Bangladesh

AEZ	Land type/depth (cm)															
	HL				MHL				MLL				LL			
	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20
1	7.00±.60	7.13±.66	6.22±.69	5.50±.69	8.79±.54	8.13±.38	8.57±.70	7.51±.87	13.06±1.15	15.88±1.54	14.53±1.25	13.30±1.24				
2	7.66±0.27	6.41±0.41	4.61±0.33	3.36±0.23	4.49±0.29	4.39±0.26	3.80±0.28	3.25±0.28								
3	4.35±.34	3.54±.34	3.17±.35	2.51±.29	6.77±.50	7.11±.84	6.05±.80	4.44±.80					7.13±1.01	7.21±1.13	6.15±1.01	5.31±.86
4	6.00±.24	5.43±.41	3.86±.40	3.03±.35	8.10±.51	5.42±.39	2.71±.24	2.08±.20					7.24±.80	5.05±.58	3.73±.44	2.66±.32
5	2.76±0.18	3.26±0.35	2.60±0.35	1.95±0.25	5.42±0.42	4.16±0.41	2.54±0.28	2.09±0.20	4.68±0.25	4.56±0.23	2.71±0.10	2.46±0.09	6.09±0.62	5.95±0.68	4.81±0.71	4.01±0.66
6									6.87±0.35	6.41±0.38	4.75±0.32	3.52±0.33	5.80±0.37	5.52±0.37	5.45±0.34	4.46±0.30
7	7.47±0.28	6.41±0.51	4.20±0.20	3.22±0.19	7.86±0.47	6.66±0.50	4.90±0.36	3.40±0.29					8.88±0.55	8.54±0.76	6.82±0.70	5.20±0.52
8	6.15±0.37	4.75±0.32	3.82±0.32	2.99±0.21	8.01±0.40	7.28±0.54	4.42±0.28	3.39±0.20					9.31±0.59	8.60±0.56	8.26±0.63	6.27±0.41
9	8.46±0.46	6.59±0.51	4.28±0.45	3.29±0.26	10.67±0.43	8.02±0.42	5.15±0.38	3.41±0.30					13.87±0.76	14.07±0.85	11.69±1.11	7.22±0.89
10*					6.18±0.66	5.39±0.56	4.74±0.58	3.79±0.52	---	---	---	---	7.22±1.28	6.88±1.31	6.16±1.32	5.37±1.21

*Note: In AEZ 10 there are four land types viz. HL, MHL, MLL & LL. But the soil samples were collected only from MHL and LL.

Table 6: Average (of 0-20 cm) soil organic carbon content (%) and soil organic carbon stock (t/ha) in different AEZs of Bangladesh

AEZ	Organic carbon content (%)				Organic carbon stock (t/ha)			
	HL	MHL	MLL	LL	HL	MHL	MLL	LL
1	0.89±.09	1.17±.08	2.10±.19		6.46±.66	8.25±.62	14.19±.129	
2	0.79±0.04	0.70±0.05			5.51±0.31	3.98±0.28		
3	0.50±.05	0.90±.09		1.05±0.15	3.39±0.33	6.09±0.74		6.45±1.00
4	0.69±0.05	0.61±0.04		0.62±0.07	4.58±0.35	4.58±0.33		4.67±0.53
5	0.45±0.04	0.47±0.04	0.54±0.03	0.71±0.08	2.64±0.28	3.55±0.33	3.60±0.17	5.22±0.67
6	---	---	0.88±0.06	1.09±0.07	---	---	5.39±0.35	5.31±0.34
7	0.80±0.04	0.86±0.06		1.17±0.09	5.32±0.29	5.70±0.40		7.36±0.63
8	0.77±0.04	0.93±0.06		1.71±0.11	4.43±0.31	5.77±0.36		8.11±0.55
9	0.82±0.05	0.96±0.05		1.64±0.11	5.65±0.42	6.81±0.38		11.71±0.90
10	---	0.72±0.08	---	1.05±0.22	---	5.03±0.58	---	6.41±1.28

*Note: In AEZ 10 there are four land types viz. HL, MHL, MLL & LL. But the soil samples were collected only from MHL and LL.

Table 7: Bulk density (g/cc) of soils at different depths in different AEZs of Bangladesh

AEZ	Land type/depth (cm)															
	HL				MHL				MLL				LL			
	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20
1	1.33±0.05	1.50±0.02	1.55±0.03	1.49±0.02	1.29±0.08	1.26±0.01	1.60±0.04	1.67±0.03	1.13±0.02	1.43±0.04	1.44±0.02	1.43±0.04				
2	1.28±0.04	1.38±0.10	1.39±0.10	1.42±0.09	1.00±0.01	1.09±0.06	1.14±0.05	1.17±0.06								
3	1.23±0.12	1.35±0.02	1.48±0.06	1.47±0.14	1.12±0.05	1.35±0.27	1.42±0.20	1.57±0.00					1.01±0.11	1.18±0.16	1.37±0.03	1.46±0.07
4	1.10±0.10	1.48±0.11	1.65±0.05	1.54±0.02	1.48±0.11	1.46±0.01	1.57±0.06	1.58±0.08					1.53±0.09	1.49±0.08	1.61±0.08	1.53±0.02
5	0.81±0.01	1.38±0.00	1.39±0.00	1.43±0.01	1.38±0.01	1.61±0.02	1.62±0.01	1.63±0.00	1.19±0.01	1.38±0.01	1.41±0.00	1.50±0.02	1.32±0.07	1.50±0.05	1.54±0.04	1.60±0.05
6	---	---	---	---	---	---	---	---	1.06±0.02	1.23±0.00	1.37±0.01	1.42±0.00	0.84±0.01	0.94±0.01	1.08±0.01	1.16±0.01
7	1.12±0.05	1.38±0.10	1.61±0.03	1.47±0.09	1.11±0.03	1.33±0.04	1.64±0.09	1.44±0.08					1.03±0.00	1.28±0.11	1.46±0.12	1.51±0.10
8	0.99±0.04	1.09±0.08	1.37±0.02	1.45±0.06	1.12±0.11	1.29±0.11	1.49±0.10	1.53±0.02					0.77±0.07	0.86±0.09	1.27±0.10	1.36±0.03
9	1.23±0.03	1.36±0.01	1.58±0.13	1.62±0.06	1.35±0.16	1.41±0.12	1.58±0.04	1.50±0.08					1.20±0.06	1.44±0.06	1.63±0.03	1.58±0.05
10*	---	---	---	---	1.33±0.04	1.39±0.01	1.44±0.02	1.48±0.01	---	---	---	---	1.20±0.04	1.25±0.03	1.26±0.03	1.31±0.03

*Note: In AEZ 10 there are four land types viz. HL, MHL, MLL & LL. But the soil samples were collected only from MHL and LL.

Table 8: Average (of 0-20 cm) soil organic carbon stock ('000 ton) in different AEZs of Bangladesh (area basis)

AEZ	Organic carbon stock ('000 ton)				Total OC stock ('000 ton (area basis))
	HL	MHL	MLL	LL	
1	1492	1117	57	0	2665
2	9	240	0	0	249
3	1123	2941	0	61	4125
4	271	518	0	12	801
5	4	24	64	289	382
6	0	0	7	41	48
7	85	673	0	188	945
8	47	144	0	43	234
9	1144	1723	0	593	3460
10	0	56	0	9	64

*Note: In AEZ 10 there are four land types viz. HL, MHL, MLL & LL. But the soil samples were collected only from MHL and LL.

Average soil organic carbon stock ('000 ton) in different AEZs (area basis)

Table 8 showed the average (of 0-20 cm) soil organic carbon stock ('000 ton) in different AEZs of Bangladesh (area basis). The soil organic carbon stock varied from 48 thousand ton (AEZ 6) to 4125 thousand ton (AEZ 3) depending on the area and land type of the respective AEZ.

The soil organic carbon SOC (%) decreased with the increase in soil depth irrespective of land types. The SOC (%) was found higher in the lowland than in the medium highland and highland. Bulk density tended to increase with increasing soil depth with certain deviation. Bulk density of medium highland varied from 1.00-1.67 g/cc where as in highland and lowland it varied from 0.81-1.65 g/cc and 0.77-1.63 g/cc, respectively. The SOC stock (t/ha) at 0-20 cm depth was higher in lowland (except AEZ-1) compared to medium highland and highland soil in irrespective of AEZs. Among the ten AEZs, the highest SOC stock (t/ha) was found in AEZ-1 irrespective of land types.

Carbon Accumulation and its Mineralization in Soils under Aerobic and Anaerobic Condition without Crop

The CO_2 emission of different organic sources and their combination with soil considered as treatments showed that the rate of CO_2 emission was higher in early period

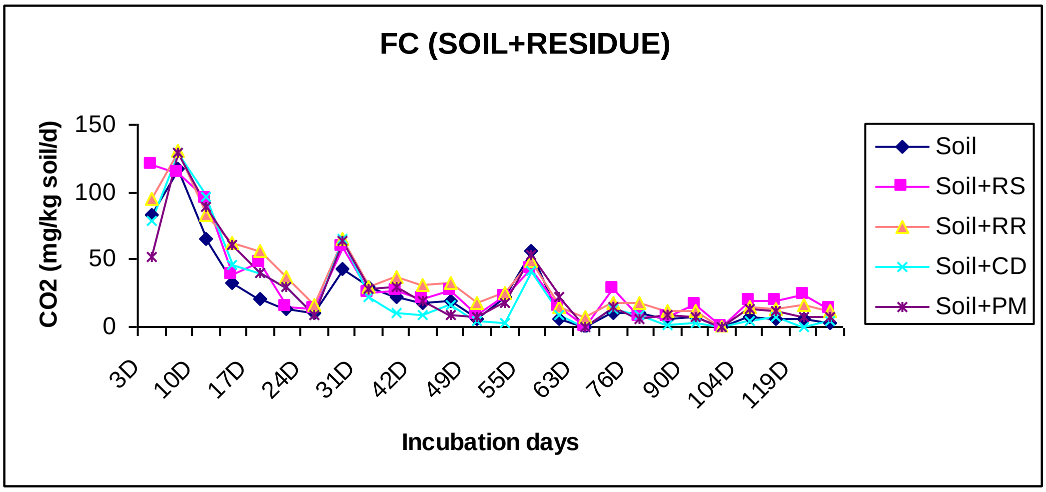

Fig.1. CO_2 emission from different organic materials with soil under flooding condition in laboratory

and subsequently decreased around 49 days and then increased at 55 days irrespective of sources and their combination in both flooding and moist condition **(Fig.1-4).** Apparently there are no sharp differences of CO_2 emission between flooding and moist condition **(Fig. 1-4).** Among the sources PM emitted more CO_2 than other sources. Results of F-probability analysis is presented in Table 9.

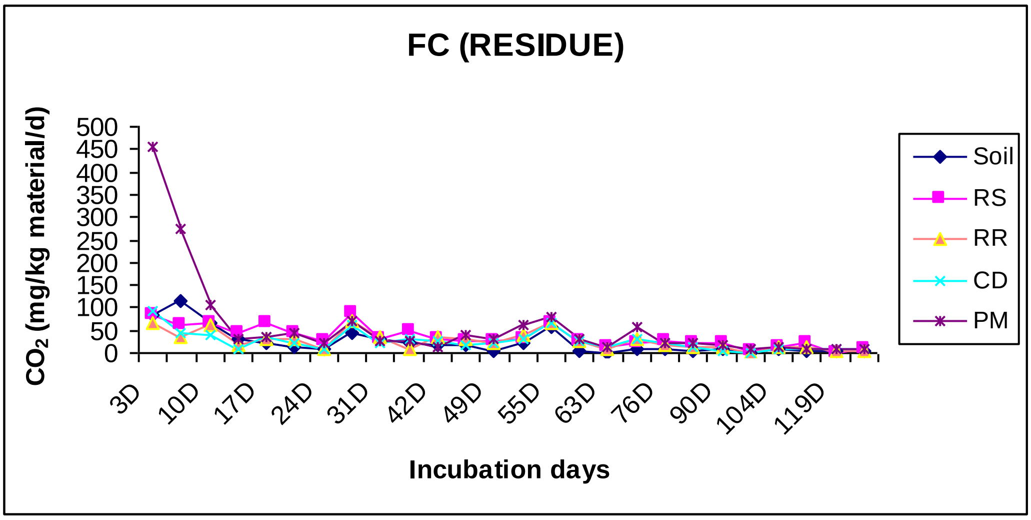

Fig.2. CO_2 emission from different organic materials without soil under flooding condition in laboratory

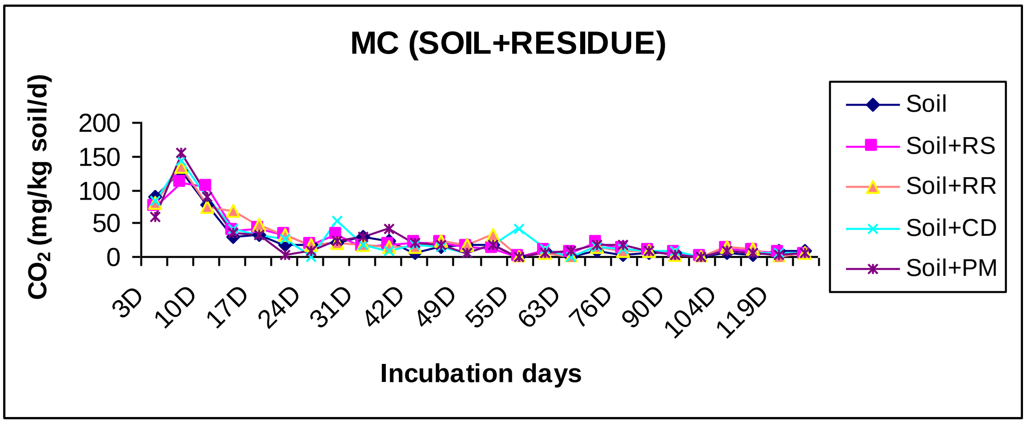

Fig.3. CO_2 emission from different organic materials with soil under moist condition in laboratory

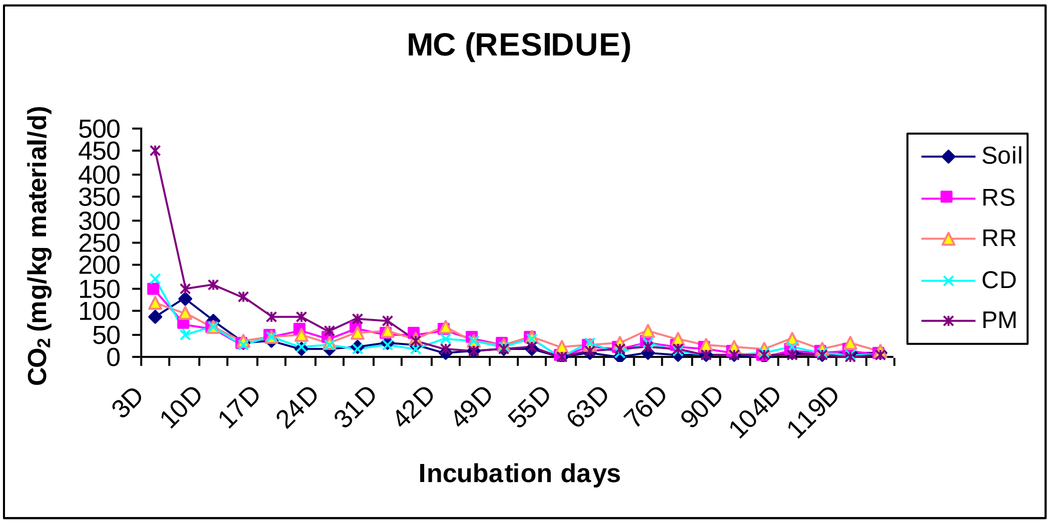

Fig.4. CO_2 emission from different organic materials without soil under moist condition in laboratory

Table 9: F-Probability analysis of CO_2 emission from different organic materials under two moisture regimes in laboratory

	F-Probability at different days of incubation																									
Source of variation	df	3D	7D	10D	14D	17D	21D	24D	28D	31D	35D	42D	46D	49D	52D	55D	59D	63D	70D	76D	84D	90D	99D	104D	115D	119D	129D
FACA	8	0.00	0.00	0.06	0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
FACB	1	0.23	1.00	0.44	0.20	0.33	0.01	0.00	0.00	0.04	0.57	0.00	0.88	0.22	0.48	0.00	0.01	0.02	0.60	0.66	0.17	0.00	0.00	0.12	0.02	0.37	0.09
REP	1	0.83	0.79	0.23	0.98	0.40	0.22	0.69	0.17	0.28	0.26	0.70	0.88	0.30	0.55	0.78	0.18	0.50	0.44	0.76	0.85	0.83	0.67	0.62	0.99	0.64	0.87
FACA*FACB	8	0.44	0.00	0.93	0.04	0.00	0.00	0.00	0.31	0.01	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.02	0.00	0.04	0.00	0.00	0.00	0.00	0.07	0.00	0.00
RESIDUAL	17																										
LSD $_{(0.05)}$ for FacAxFacB		NS	22.2	NS	48.1	20.5	13.7	12.5	NS	22.5	13.3	7.1	11.1	NS	13.7	17.0	8.0	8.5	8.1	13.0	5.5	5.3	3.0	7.6	7.4	5.63	5.05
CV%		29	9.1	37.5	53.3	22.2	19.7	31.2	29	33.7	23.1	13.3	21.5	26.5	23.7	24.7	21.7	49.5	15.6	38.8	23.6	26.3	55.7	27.2	33.9	34.6	33.5

Table 10: Apparent carbon balance under different residues and moisture regimes

Treatment		C input (g/kg)			C output (g/kg)			C balance
Fac A	Fac B	Soil C	Residue C	Total	Emission	Residual	Total	(g/kg)
Soil	FC	11	0	11	0.65	7.42	8.07	2.93
Soil +RS	FC	11	2.5	13.5	0.93	8.49	9.42	4.08
Soil +RR	FC	11	2.5	13.5	1.01	8.30	9.30	4.20
Soil +CD	FC	11	2.5	13.5	0.68	8.20	8.88	4.62
Soil +PM	FC	11	2.5	13.5	0.80	8.30	9.10	4.40
RS	FC	0	2.5	2.5	1.04	1.67	2.71	-0.21
RR	FC	0	2.5	2.5	0.83	1.71	2.53	-0.03
CD	FC	0	2.5	2.5	0.75	1.38	2.13	0.37
PM	FC	0	2.5	2.5	1.59	1.40	2.99	-0.49
Soil	MC	11	0	11	0.61	6.44	7.05	3.95
Soil +RS	MC	11	2.5	13.5	0.71	7.81	8.52	4.98
Soil +RR	MC	11	2.5	13.5	0.73	7.91	8.64	4.86
Soil +CD	MC	11	2.5	13.5	0.74	7.91	8.64	4.86
Soil +PM	MC	11	2.5	13.5	0.70	9.47	10.16	3.34
RS	MC	0	2.5	2.5	1.03	1.27	2.30	0.20
RR	MC	0	2.5	2.5	1.34	1.73	3.07	-0.57
CD	MC	0	2.5	2.5	0.82	1.17	1.98	0.52
PM	MC	0	2.5	2.5	1.47	1.04	2.51	-0.01
LSD (0.05) for FacAxFacB	-	-	-	-	0.15	NS	NS	NS
CV%	-	-	-	-	7.7	14.8	12.6	32.5

The emission of CO_2 was significantly influenced by sources of i.e. residues and manures under different moisture regimes (Table 10). However, the interaction effect of carbon source and moisture regimes on carbon dioxide emission was found significant. Though the carbon contents in the rice straw and even in the roots were high, the emission of carbon dioxide was higher only in the poultry manure without soil. During 129 days of incubation the highest total amount of carbon dioxide released from only PM containing pot was 1.59 g/kg in flooding condition and 1.47 g/kg in moist condition which was significantly different from the treatment PM mixed with soil in both condition. The total emission of carbon dioxide over the 129 days of incubation under controlled treatment i.e. in the pot where only 100 g soil used was almost same under both conditions (Table 10).

The sources of carbon i.e. the residues significantly affected carbon balance while interaction effect of residues and moisture regimes was found insignificant (Table 10 and 11). When plant residues and manures are applied to the soil various organic compounds undergo decomposition. The addition of residues and manures to the soil surface contributes to the biological activity and the carbon cycling process in the soil.

Table 11: Apparent carbon balance under different residues

Treatment	C input (g/kg)			C output (g/kg)			C balance (g/kg)
Fac A	Soil C	Residue C	Total	Emission	Residual	Total	
Soil	11	0	11	0.6	6.9	7.6	3.4
Soil +RS	11	2.5	13.5	0.8	8.1	9.0	4.5
Soil +RR	11	2.5	13.5	0.9	8.1	9.0	4.5
Soil +CD	11	2.5	13.5	0.7	8.1	8.8	4.7
Soil +PM	11	2.5	13.5	0.8	8.9	9.6	3.9
RS	0	2.5	2.5	1.0	1.5	2.5	0.0
RR	0	2.5	2.5	1.1	1.7	2.8	-0.3
CD	0	2.5	2.5	0.8	1.3	2.1	0.4
PM	0	2.5	2.5	1.5	1.2	2.8	-0.3
LSD $_{(0.05)}$ for FacA	-	-	-	0.10	1.12	1.13	1.13
CV%	-	-	-	7.7	14.8	12.6	32.5

The rate of CO_2 emission was higher in earlier stage of incubation irrespective of organic sources in both flooding and moist condition. However, PM emitted more CO_2 than CD, RS and RR alone.

Carbon Accumulation and its Mineralization in Soils under Aerobic and Anaerobic Condition with Rice

Effect of different organic residues, carbon rates and moisture regime on soil pH

The different organic residues significantly affected soil pH at 30, 60 and 180 days of incubation of the experiment (Table 12). At 30 and 60 days of incubation the poultry litter was found more efficient to increase the soil pH level significantly than others. On the other hand at180 days of incubation it was found that poultry litter, cow dung and rice straw showed significantly higher effect to increase soil pH than rice root (Table 12). It is reported that poultry litter contained high level of calcium (Ca), which has the potentiality to increase soil pH. Poultry diet contained di-calcium phosphate, which leads to increase Ca levels significantly in the litter. Therefore, poultry litter has liming effect (MSU, 2009). The effectiveness of poultry litter as liming material was 26% compared to lime (Materechera and Mkhabela, 2002). Cow dung increases microbial respiration and soil pH (Olayinka, 2001). Cow dung showed its efficiency to increase soil pH at 180 days of incubation, while the rest time of the experiment the effect was not significant at same level. Same trend was also observed in case of rice straw.

Carbon rates of organic residues showed significant effects on soil pH at 30, 60, 90, 120 and 180 days of incubation, while the effect was insignificant at 150 days of incubation (Table 12). It was found that the soil pH increased more when the carbon rate was more i.e. 1.5 and 2.0 t C/ha. Reason might be due to the addition of more Ca enriched poultry litter.

Moisture regime showed a significant effect on soil pH at 30, 90, 120 and 180 days of incubation, while the effect was insignificant at 60 and 150 days of incubation (Table 12). Alternate wetting and drying (AWD) condition showed a significant effect on the soil pH at 90 days, while continuous standing water (CSW) condition was significant at 30, 120 and 180 days of incubation.

Effect of different organic residues, carbon rates and moisture regime on soil organic carbon

The different organic residues did not affect significantly on soil organic carbon (SOC) at all intervals of the incubation of the experiment in net house condition (Table 13).

Table 12: Effect of different organic residues, carbon rate and moisture regime on soil pH at different interval of incubation

Treatment	Soil pH					
	30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
Residues						
Rice straw	5.43b	5.71b	6.10	5.77	5.82	6.00ab
Rice root	5.47b	5.68b	6.05	5.73	5.57	5.96b
Cow dung	5.44b	5.72b	6.08	5.74	5.79	6.01ab
Poultry litter	5.55a	5.80a	6.12	5.78	5.86	6.07a
F-Test	**	**	NS	NS	NS	**
CV (%)	1.6	1.8	1.7	2.1	9.6	2.2
Carbon rate (t/ha)						
0.0	5.41bc	5.71b	5.91d	5.65c	5.67	5.87c
0.5	5.39c	5.64c	6.06c	5.72bc	5.79	5.98b
1.0	5.45b	5.72b	6.14ab	5.76b	5.61	6.06ab
1.5	5.54a	5.76ab	6.13b	5.80ab	5.84	6.02b
2.0	5.58a	5.80a	6.20a	5.86a	5.88	6.13a
F-Test	**	**	**	**	NS	**
CV (%)	1.6	1.8	1.7	2.1	9.6	2.2
Water regime						
AWD	5.44b	5.74	6.12a	5.73b	5.79	5.96b
CSW	5.51a	5.72	6.05b	5.78a	5.73	6.06a
F-Test	**	NS	**	*	NS	**
CV (%)	1.6	1.8	1.7	2.1	9.6	2.2

The SOC decreased slightly with increased the crop growth duration due to increasing temperature irrespective of all residues used in the experiment and carbon rates (Fig. 5 and Table 13). Monika *et. al.* 2002 also observed that the rate of CO_2-C emission and organic matter decomposition increased with increasing temperature which is attributed to the depletion of soil carbon. They further noted that 1˚ C increase in temperature could lead to a loss of 10% of soil organic carbon. It might be the reason in case of the depletion of SOC in net house experiment which we conducted. The same trend was also found in case of carbon rates of organic residues (Table 13).

The moisture regime showed significant effect on SOC at 60 days of incubation, while the effect was insignificant at the rest intervals. Continuous standing water (CSW) condition was found more efficient to accumulate SOC in soils (Table 13).

Table 13: Effect of different organic residues, carbon rate and water regime on soil organic carbon at different interval of incubation

Treatment	Soil organic carbon (%)					
	30 days	60 days	90 days	120 days	150 days	180 days
Residues						
Rice straw	1.16	1.14	0.87	0.69	0.68	0.82
Rice root	1.12	1.15	0.86	0.74	0.67	0.79
Cow dung	1.10	1.16	0.92	0.71	0.66	0.84
Poultry litter	1.13	1.15	0.90	0.74	0.68	0.85
F-Test	NS	NS	NS	NS	NS	NS
CV (%)	11.9	7.7	11.1	21.9	14.7	15.3
Carbon rate (t/ha)						
0.0	1.12	1.12	0.87	0.78	0.67	0.80
0.5	1.11	1.12	0.88	0.72	0.66	0.79
1.0	1.13	1.16	0.88	0.69	0.68	0.82
1.5	1.11	1.16	0.89	0.71	0.72	0.84
2.0	1.16	1.19	0.92	0.71	0.65	0.87
F-Test	NS	NS	NS	NS	NS	NS
CV (%)	11.9	7.7	11.1	21.9	14.7	15.3
Water regime						
AWD	1.11	1.13b	0.88	0.73	0.67	0.81
CSW	1.14	1.17a	0.90	0.71	0.68	0.84
F-Test	NS	*	NS	NS	NS	NS
CV (%)	11.9	7.7	11.1	21.9	14.7	15.3

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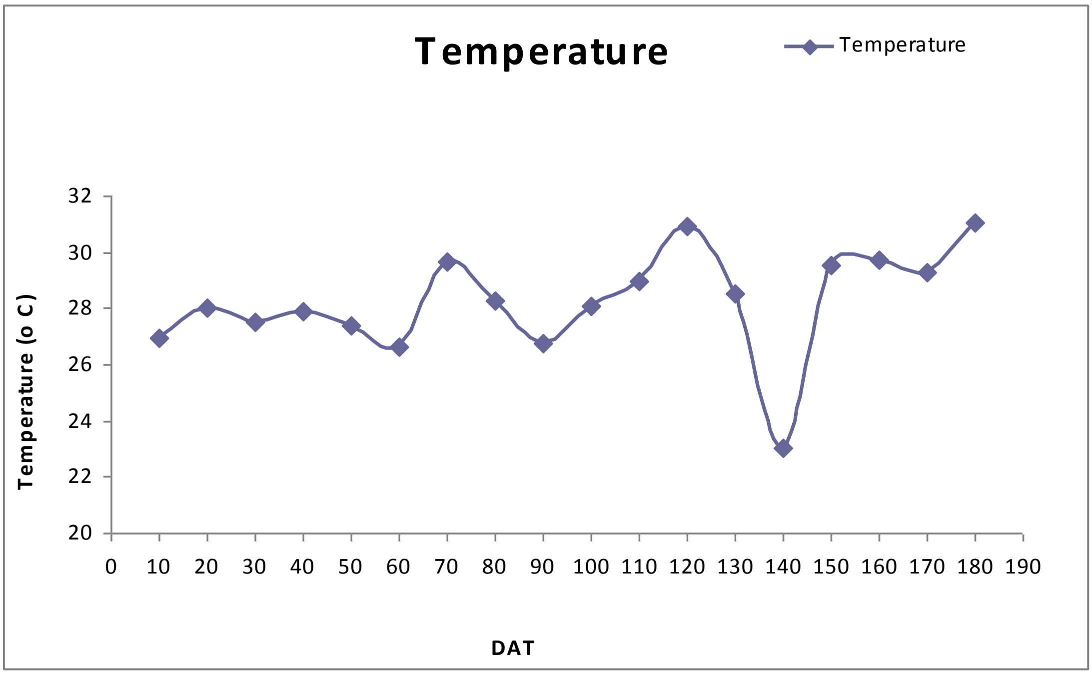

Fig.5: Day temperature of the growing period of rice at net house condition, BRRI, Gazipur, 2011

At 30 and 60 days of incubation the poultry litter was found more efficient to increase the soil pH level significantly than others. On the other hand at180 days of incubation it was found that poultry litter, cow dung and rice straw showed significantly higher effect to increase soil pH than rice root. It was found that the soil pH increased more when the carbon rate was more i.e. 1.5 and 2.0 t C/ha. Alternate wetting and drying (AWD) condition showed a significant effect on the soil pH at 90 days, while continuous standing water (CSW) condition was significant at 30, 120 and 180 days of incubation. The SOC decreased slightly with increased the crop growth duration due to increasing temperature irrespective of all residues used in the experiment and carbon rates. Continuous standing water (CSW) condition was found more efficient to accumulate SOC in soils.

Carbon sequestration in soils under different tillage and rice straw management

Carbon dioxide emission (kg CO_2/ha/day) from rice field

T. Aman season

In T. Aman 2011 carbon dioxide emission was measured after eight weeks of transplanting and continued up to 16 weeks after transplanting. Results are presented in Table 14. From the Table 14 it is shown that tillage operations showed significant effect on carbon dioxide emission from rice soil at 15th and 16th weeks after transplanting and at the rest weeks were insignificant. The higher significant CO_2 emission from soil ($p<0.05$) was observed in case of minimum tillage operation at 15th & 16th weeks measurement (Table 14). Rice straw management practices showed significant effect on CO_2 emission from soil ($p<0.01$) only at 14th weeks after transplanting. In this measurement, the amount of CO_2 released was significantly higher (41.15 kg CO_2/ha/day) in rice straw incorporated soil over the rice straw surface mulch practice (36.96 kg CO_2/ha/day), while in control plot it was 27.53 kg CO_2/ha/day. These results are in agreement with those of Monika *et al.*, 2002.

In T. Aman 2012 carbon dioxide emission was measured after 1st week of transplanting and continued up to 17 weeks after transplanting. Results are presented in Table 15. From the Table 15 it is shown that tillage operations showed significant effect on carbon dioxide emission from rice soil at 12th weeks after transplanting and at the rest weeks were insignificant. The higher significant CO_2 emission from soil ($p<0.05$) was observed in case of traditional tillage operation at 12th weeks measurement (Table 15). Rice straw management practices showed significant effect on CO_2 emission from soil ($p<0.01$) at 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th 11th, 12th, 13th & 14th weeks after transplanting. In this measurement, the amount of CO_2 released was significantly higher in rice straw surface mulch (SRS) soil over the rice straw incorporation practice, while in control plot it was comparatively lower (Table 15). These results are in agreement with those of Monika *et al.*, 2002.

In T. Aman 2013 carbon dioxide emission was measured after 1st week of transplanting and continued up to 15 weeks after transplanting. Results are presented in Table 16.

From the Table 16 it is shown that there was no effect of tillage operations and rice straw management practices on carbon dioxide emission from rice soil.

There was no significant interaction effect of tillage method and rice straw management on CO_2 (kg/ha/day) emission from the rice field in both T. Aman 2011 & 2013 (Table 17 & 19). But in T. Aman 2012, there was significant interaction effect of tillage method and rice straw management on CO_2 emission from rice soil at 6^{th} weeks after transplanting and at the rest weeks were insignificant. The higher significant CO_2 emission from soil ($p<0.05$) was observed in case of minimum tillage X rice straw surface mulch at 6^{th} week of measurement (Table 18).

Boro season

In Boro 2011-12, tillage operations showed significant effect on carbon dioxide emission from rice soil only at eighth week after transplanting and the rest weeks were insignificant. The higher significant CO_2 emission from soil ($p<0.01$) was observed in case of minimum tillage operation at eighth week measurement (Table 20). This result is quite similar to those of T. Aman 2011.

None of the rice straw management practices showed significant effect on CO_2 emission from soil during the crop growing Boro season 2011-12 (Table 20). Such result might be due to the low temperature (Monika *et al.*, 2002) at Boro season.

There was no significant interaction effect of tillage method and rice straw management on CO_2 (kg/ha/day) emission from the rice field in Boro 2011-12 seasons (Table 21).

Cumulative CO_2 (kg/ha) emission from the rice field

T. Aman season

The cumulative emissions of CO_2 under different tillage and rice straw management practices in T. Aman 2011, 2012 & 2013 are presented in Table 22, 23 and 24. Tillage operations and rice straw management practices did not show significant effect on cumulative CO_2 emission in both T. Aman of 2011 & 2013 seasons (Table 22 & 24). In T. Aman 2012 Tillage operations did not show significant effect on cumulative CO_2 emission but the rice straw management practices showed significant effect on

Table 14: CO_2 (kg/ha/day) emission from the rice field with different tillage and rice straw management (T. Aman 11)

Treatment	Weeks after transplanting															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
Tillage method																
Min. tillage	nd	nd	nd	nd	nd	nd	nd	nd	54.70	68.99	52.10	39.45	41.78	35.76	87.61a	49.86a
Trad. tillage	nd	nd	nd	nd	nd	nd	nd	nd	51.29	63.95	51.12	37.80	39.46	34.67	74.00b	42.21b
F-test	nd	nd	nd	nd	nd	nd	nd	nd	NS	NS	NS	NS	NS	NS	*	*
CV%	nd	nd	nd	nd	nd	nd	nd	nd	15.7	15.5	18.1	23.2	9.4	4.0	11.5	10.0
Straw management																
Control	nd	nd	nd	nd	nd	nd	nd	nd	51.46	61.07	47.06	32.64	37.67	27.53c	76.03	43.28
RS Incor.	nd	nd	nd	nd	nd	nd	nd	nd	57.12	68.64	55.19	46.10	41.65	41.15a	81.08	45.89
RS Mulch	nd	nd	nd	nd	nd	nd	nd	nd	50.41	69.70	52.59	37.13	42.53	36.96b	85.30	48.92
F-test	nd	nd	nd	nd	nd	nd	nd	nd	NS	NS	NS	NS	NS	**	NS	NS
CV%	nd	nd	nd	nd	nd	nd	nd	nd	15.7	15.5	18.1	23.2	9.4	4.0	11.5	10.0

Table 15: CO_2 (kg/ha/day) emission from the rice field with different tillage and rice straw management (T. Aman 12)

Treatment	Weeks after transplanting																
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th
Tillage Method																	
Min. tillage	28.48	33.23	47.72	25.70	29.38	39.29	41.44	36.69	41.14	42.67	38.70	31.58b	20.09	32.43	30.88	19.32	26.37
Trad. tillage	31.64	36.91	55.47	25.65	29.32	42.28	39.49	38.15	37.06	40.74	36.75	34.43a	21.85	30.03	26.55	20.07	25.14
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
CV%	23.8	23.8	17.8	10.7	10.7	10.1	13.1	13.7	11.6	13.4	10.5	7.9	21.1	25.2	33.9	18.5	39
Rice Straw Management																	
Control	31.14	36.32	43.07b	22.73b	25.98b	36.12b	33.48b	32.18b	36.12b	37.03b	34.47b	32.56ab	15.13b	24.51b	22.17	19.19	20.07
RS Incor.	31.34	36.57	50.11ab	25.56ab	29.21ab	40.10b	42.66a	36.92ab	38.38ab	43.52ab	37.74ab	35.54a	26.02a	34.70a	28.87	21.83	27.95
RS Mulch	27.70	32.32	61.60a	28.75a	32.85a	46.14a	45.26a	43.16a	42.78a	44.55a	40.97a	30.93b	21.75a	34.49ab	35.12	18.06	29.25
F-test	NS	NS	*	**	**	**	**	**	**	*	*	*	**	*	NS	NS	NS
CV%	23.8	23.8	17.8	10.7	10.7	10.1	13.1	13.7	11.6	13.4	10.5	7.9	21.1	25.2	33.9	18.5	39

Table 16: CO_2 (kg/ha/day) emission from the rice field with different tillage and rice straw management (T. Aman 13)

Treatment	Weeks after transplanting														
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th
Tillage method															
Min. tillage	42.42	35.41	40.34	41.56	44.35	45.89	39.24	48.18	41.53	39.49	42.73	48.01	26.73	34.11	44.07
Trad. tillage	45.49	40.79	48.27	48.32	43.09	48.76	41.00	45.77	39.04	41.23	44.96	51.70	26.17	39.28	45.61
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	19.3	19.6	19.8	28	16.3	16.4	18.5	12.7	23.1	15.1	17.9	11.7	22.6	21.1	21.6
Straw management															
Control	46.35	36.15	43.16	44.38	46.35	46.39	40.06	45.72	38.05	39.80	43.12	47.06	24.25	37.88	47.77
RS Incor.	45.80	40.99	42.28	40.90	42.03	43.92	37.55	46.35	43.37	40.51	44.04	50.87	27.48	35.79	43.92
RS Mulch	39.73	37.14	47.48	49.53	42.78	51.67	42.74	48.86	39.43	40.77	44.38	51.63	27.62	36.42	42.83
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	19.3	19.6	19.8	28	16.3	16.4	18.5	12.7	23.1	15.1	17.9	11.7	22.6	21.1	21.6

Table 17: Interaction effect of tillage method and rice straw management on CO_2 (kg/ha/day) emission from the rice field (T. Aman 2011)

Treatment		**Weeks after transplanting**															
Tillage	RS mangt.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Min. tillage	Control	nd	nd	nd	nd	nd	nd	nd	nd	56.24	70.05	47.02	32.69	38.59	29.33	81.08	45.99
	RS Incor.	nd	nd	nd	nd	nd	nd	nd	nd	61.60	70.75	57.49	46.43	43.20	40.82	96.10	54.14
	RS Mulch	nd	nd	nd	nd	nd	nd	nd	nd	46.26	66.18	51.79	39.22	43.54	37.13	85.65	49.44
Trad. tillage	Control	nd	nd	nd	nd	nd	nd	nd	nd	46.68	52.10	47.10	32.60	36.75	25.73	70.99	40.58
	RS Incor.	nd	nd	nd	nd	nd	nd	nd	nd	52.63	66.53	52.88	45.76	40.10	41.49	66.06	37.64
	RS Mulch	nd	nd	nd	nd	nd	nd	nd	nd	54.56	73.22	53.39	35.03	41.53	36.79	84.95	48.40
F-Test		nd	nd	nd	nd	nd	nd	nd	nd	NS	NS	NS	NS	NS	NS	NS	NS
CV%		nd	nd	nd	nd	nd	nd	nd	nd	15.7	15.5	18.1	23.2	9.4	4.0	11.5	10.0

Table 18: Interaction effect of tillage method and rice straw management on CO_2 (kg/ha/day) emission from the rice field (T. Aman 2012)

Treatment		Weeks after transplanting																
Tillage	RS mangt.	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th
Min. tillage	Control	26.19	30.56	33.24	21.01	24.01	29.63c	35.41	32.64	38.43	39.64	36.03	30.88	12.57	26.82	26.11	18.23	22.13
	RS Incor.	28.62	33.39	46.93	25.26	28.87	39.60b	40.19	31.97	39.60	43.82	36.62	35.24	22.96	33.61	27.20	20.83	25.06
	RS Mulch	30.63	35.74	62.97	30.84	35.24	48.65a	48.74	45.47	45.38	44.55	43.46	28.62	24.72	36.88	39.35	18.90	31.93
Trad. tillage	Control	36.08	42.09	52.90	24.46	27.95	42.62ab	31.55	31.72	33.82	34.43	32.90	34.24	17.68	22.21	18.23	20.16	18.02
	RS Incor.	34.07	39.75	53.29	25.85	29.54	40.61b	45.13	41.86	37.17	43.23	38.87	35.83	29.08	35.79	30.55	22.84	30.84
	RS Mulch	24.77	28.89	60.23	26.66	30.46	43.62ab	41.78	40.86	40.19	44.55	38.48	33.23	18.77	32.10	30.88	17.22	26.57
F-Test		NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%		23.8	23.8	17.8	10.7	10.7	10.1	13.1	13.7	11.6	13.4	10.5	7.9	21.1	25.2	33.9	18.5	39

Table 19: Interaction effect of tillage method and rice straw management on CO_2 (kg/ha/day) emission from the rice field (T. Aman 2013)

Treatment		Weeks after transplanting														
Tillage	RS mangt.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Min. tillage	Control	46.05	39.78	38.22	42.45	39.60	45.80	39.18	50.66	41.28	40.64	44.21	50.75	25.62	33.61	44.63
	RS Incor.	41.61	30.98	36.88	36.33	45.05	42.62	32.64	43.04	36.75	34.39	36.16	39.94	27.57	29.00	44.96
	RS Mulch	39.60	35.46	45.93	45.89	48.40	49.24	45.89	50.83	46.56	43.45	47.81	53.34	26.99	39.73	42.62
Trad. tillage	Control	45.55	42.20	46.35	39.35	44.46	42.03	35.91	42.03	45.47	40.38	43.87	51.00	29.33	37.97	43.20
	RS Incor.	51.08	41.32	49.45	52.42	47.65	50.16	47.48	48.40	39.35	45.21	50.08	54.18	20.92	46.77	50.58
	RS Mulch	39.85	38.83	49.03	53.18	37.17	54.10	39.60	46.89	32.31	38.10	40.94	49.91	28.26	33.10	43.04
F-Test		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%		19.3	19.6	19.8	28	16.3	16.4	18.5	12.7	23.1	15.1	17.9	11.7	22.6	21.1	21.6

Table 20: CO_2 (kg/ha/day) emission from the rice field with different tillage and rice straw management (Boro 2011-12)

Treatment	Weeks after transplanting															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
Tillage method																
Min. tillage	8.46	11.22	10.99	19.42	31.39	33.01	32.71	67.62a	38.79	36.23	29.26	32.80	30.39	33.90	26.84	30.07
Trad. tillage	7.35	13.31	14.07	22.07	30.35	33.31	32.80	57.79b	39.35	35.03	28.73	35.79	30.90	34.49	27.42	33.34
F-test	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
CV%	50.5	22.9	43.2	26.5	22.9	18.5	14.9	13.1	13.8	10.5	12.4	16.7	15.0	16.7	8.2	16.9
Straw management																
Control	8.16	11.61	11.36	19.28	30.72	31.81	31.01	59.17	36.96	33.61	27.99	32.90	28.54	30.97	25.54	29.33
RS Incor.	9.53	12.99	14.50	23.30	34.49	36.29	36.42	62.52	41.61	36.62	29.21	37.09	32.39	36.42	28.41	32.31
RS Mulch	6.01	12.19	11.73	19.65	27.41	31.39	30.84	66.42	38.64	36.67	29.79	32.90	31.01	35.20	27.44	33.48
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	50.5	22.9	43.2	26.5	22.9	18.5	14.9	13.1	13.8	10.5	12.4	16.7	15.0	16.7	8.2	16.9

Table 21: Interaction effect of tillage method and rice straw management on CO_2 (kg/ha/day) emission from the rice field (Boro 2011-12)

Treatment		Weeks after transplanting															
Tillage	RS mangt.	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
Min. tillage	Control	8.46	9.09	8.17	18.27	30.80	30.72	31.26	62.65	35.91	34.28	28.12	29.84	27.99	31.30	25.02	29.04
	RS Incor.	11.98	13.37	15.30	24.14	36.42	39.60	38.97	73.12	43.04	38.22	29.71	36.62	33.52	36.50	28.68	31.14
	RS Mulch	4.94	11.19	9.51	15.84	26.94	28.70	27.91	67.09	37.42	36.21	29.96	31.93	29.67	33.90	26.83	30.05
Trad. tillage	Control	7.87	14.12	14.54	20.28	30.63	32.90	30.76	55.69	38.01	32.94	27.87	35.95	29.08	30.63	26.06	29.63
	RS Incor.	7.09	12.61	13.70	22.46	32.56	32.98	33.86	51.92	40.19	35.03	28.70	37.55	31.26	36.33	28.14	33.48
	RS Mulch	7.09	13.20	13.95	23.47	27.87	34.07	33.78	65.75	39.85	37.13	29.63	33.86	32.35	36.50	28.05	36.92
F-Test		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%		64.0	25.8	48.4	29.5	29.6	22.0	12.8	9.4	5.0	14.6	5.6	14.6	8.0	10.6	3.9	17.5

Table 22: Cumulative CO_2 (kg/ha) emission from the rice field with different tillage and rice straw management T. Aman 2011

Treatment	Weeks after transplanting															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
Tillage method																
Min. tillage	nd	nd	nd	nd	nd	nd	nd	nd	383	728	1093	1369	1661	1911	2350	2798
Trad. tillage	nd	nd	nd	nd	nd	nd	nd	nd	359	679	1037	1301	1577	1820	2190	2570
F-Test	nd	nd	nd	nd	nd	nd	nd	nd	NS	NS	NS	NS	NS	NS	NS	NS
CV%	nd	nd	nd	nd	nd	nd	nd	nd	12.8	12.2	12.7	15.3	13.8	13.2	12.4	12.0
Straw management																
Control	nd	nd	nd	nd	nd	nd	nd	nd	360	666	995	1223	1487	1680	2060	2450
RS Incor.	nd	nd	nd	nd	nd	nd	nd	nd	400	743	1129	1452	1744	2032	2437	2850
RS Mulch	nd	nd	nd	nd	nd	nd	nd	nd	353	701	1069	1329	1627	1886	2312	2753
F-Test	nd	nd	nd	nd	nd	nd	nd	nd	NS	NS	NS	NS	NS	NS	NS	NS
CV%	nd	nd	nd	nd	nd	nd	nd	nd	12.8	12.2	12.7	15.3	13.8	13.2	12.4	12.0

Table 23: Cumulative CO_2 (kg/ha) emission from the rice field with different tillage and rice straw management T. Aman 2012

Treatment	Weeks after transplanting																
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th
Tillage Method																	
Min. tillage	199	399	685	891	1096	1371	1661	1918	2206	2548	2780	3001	3142	3369	3585	3720	3905
Trad. tillage	221	443	776	981	1186	1482	1759	2026	2285	2611	2831	3072	3225	3436	3621	3762	3938
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	23.8	23.8	18.6	15.8	14.2	13	10.7	10.4	9.2	8	7.6	6.9	6.8	7.4	8.5	8.3	8.8
Rice Straw Management																	
Control	218	436	694	876	1058	1311	1545b	1771b	2023b	2320b	2526b	2754b	2860b	3032b	3187b	3321b	3462b
RS Incor.	219	439	739	944	1148	1429	1728ab	1986ab	2255ab	2603a	2829a	3078a	3260a	3503a	3705a	3858a	4054a
RS Mulch	194	388	757	987	1217	1540	1857a	2159a	2459a	2815a	3061a	3277a	3430a	3671a	3917a	4043a	4248a
F-test	NS	NS	NS	NS	NS	NS	*	*	**	**	**	**	**	**	**	**	**
CV%	23.8	23.8	18.6	15.8	14.2	13	10.7	10.4	9.2	8	7.6	6.9	6.8	7.4	8.5	8.3	8.8

Table 24: Cumulative CO_2 (kg/ha) emission from the rice field with different tillage and rice straw management T. Aman 2013

Treatment															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th
Tillage method															
Min. tillage	297	580	863	1153	1464	1785	2060	2397	2688	3043	3342	3678	3839	4077	4386
Trad. tillage	318	645	983	1321	1623	1964	2251	2571	2845	3216	3530	3892	4049	4324	4643
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	19.3	16.8	16.5	18.5	16.6	16.3	15.9	14.6	13	11.8	11.3	10.4	9.9	9.5	9.5
Straw management															
Control	321	649	945	1231	1525	1832	2095	2420	2723	3088	3396	3752	3917	4168	4475
RS Incor.	324	614	916	1226	1551	1876	2156	2476	2742	3101	3402	3732	3877	4142	4477
RS Mulch	278	575	908	1254	1554	1915	2215	2557	2833	3200	3510	3872	4037	4292	4592
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	19.3	16.8	16.5	18.5	16.6	16.3	15.9	14.6	13	11.8	11.3	10.4	9.9	9.5	9.5

Table 25: Cumulative CO_2 (kg/ha) emission from the rice field with different tillage and rice straw management Boro 2011-12

Treatment	Weeks after transplanting															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
Tillage method																
Min. tillage	51	129	206	342	562	793	1022	1495	1767	2020	2225	2455	2668	2905	3254	3464
Trad. tillage	44	137	236	390	603	836	1065	1470	1745	1991	2192	2442	2659	2900	3256	3490
F-Test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	50.5	26.2	31.3	25.6	23.4	21.3	18.7	13.9	12.9	11.7	11.4	11.1	10.9	10.9	10.5	10.1
Straw management																
Control	49	130	210	345	560	782	999	1414	1672	1908	2103	2334	2534	2750	3082	3288
RS Incor.	57	148	250	413	654	908	1163	1601	1892	2148	2353	2612	2839	3094	3463	3690
RS Mulch	36	121	204	341	533	753	969	1434	1704	1961	2169	2399	2617	2863	3220	3454
F-Test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	50.5	26.2	31.3	25.6	23.4	21.3	18.7	13.9	12.9	11.7	11.4	11.1	10.9	10.9	10.5	10.1

cumulative CO_2 emission from soil ($p<0.01$) at 7th to 17th weeks after transplanting. In this measurement, the amount of cumulative CO_2 released was significantly higher in rice straw surface mulch (SRS) and rice straw incorporation (IRS) over the control plot (Table 23).

Boro season

The cumulative emissions of CO_2 under different tillage and rice straw management practices in Boro 2011-12 is presented in Table 25. Tillage operations and rice straw management practices did not show significant effect on cumulative CO_2 emission.

Total CO_2 emissions from the rice field (T. Aman 2012, 2013 & Boro 2011-12)

The total emissions of CO_2 under different tillage operations and rice straw management practices in T. Aman 2012, 2013 & Boro 2011-12 are presented in Table 26. Tillage operations did not show significant effect on carbon dioxide emission from soil (Table 26) but rice straw management practices showed significant effect on carbon dioxide emissions from soil in T. Aman 2012 (Table 26). In this measurement, the amount of total CO_2 released was significantly higher (4248 kg CO_2/ha/115 days in RS mulch & 4054 kg/ha/115days in RS incorporation) over the control (3462 kg CO_2/ha/115 days).

Table 26: Total CO_2 emissions from the rice field (T. Aman 2012, 2013 & Boro 2011-12)

	T. Aman			Boro
	2012	2013		2011-12
Treatment	Total CO_2 emission (kg/ha/115 days)	Total CO_2 emission (kg/ha/112 days)	Average Total CO_2 emission (kg/ha/114 days)	Total CO_2 emission (kg/ha/112 days)
Tillage method				
Min. tillage	3905	4386	4146	3464
Trad. tillage	3938	4643	4291	3490
F-test	NS	NS	--	NS
CV%	8.8	9.5	--	10.1
Straw management				
Control	3462b	4475	3969	3288
RS Incor.	4054a	4477	4266	3690
RS Mulch	4248a	4592	4420	3454
F-test	**	NS	--	NS
CV%	8.8	9.5	--	10.1

From Table 26 it is shown that the total amount of released CO_2 was higher in T. Aman season than that of Boro season. Results might be due to the comparatively higher temperature (Monika *et al*., 2002) prevails in T. Aman season than Boro season.

Effect of tillage operations and rice straw management practices on soil nutrient status

The effect of tillage operations on SOC (%), total N%, available P, exchangeable K and available Zn after harvesting of 5th crop (T. Aman rice) was found insignificant except pH (Table 27). On the other hand the rice straw management practices showed the significant effect on pH, total N% and available Zn. From the Table 27 it is shown that the significantly higher pH (6.47) was observed in Traditional tillage than Minimum tillage (6.43). In case of rice straw management practices the significantly highest pH (6.50) was observed in control (without rice straw) plot followed by SRS and the lowest in RS incor.. The significantly higher (0.14%) total N was found in SRS and the lowest on control. In case of available Zn the significantly highest (1.21 mg/kg) was found in rice straw incorporation and the lowest in control.

Table 27: Effect of tillage operations and rice straw management practices on some soil nutrients (T. Aman rice 2012)

Treatment	pH (1:2.5)	SOC (%)	Total N (%)	Available P (mg/kg)	Exchangeable K (Cmol/kg soil)	Available Zn (mg/kg)
Tillage method						
Min. tillage	6.43b	1.61	0.13	2.98	0.23	1.07
Trad. tillage	6.47a	1.67	0.12	3.60	0.22	1.05
F-test	**	NS	NS	NS	NS	NS
CV%	0.3	8.9	12.5	35.9	12.3	8.7
Straw management						
Control	6.50a	1.57	0.11b	3.23	0.22	0.89c
RS Incor.	6.41c	1.68	0.12ab	4.03	0.22	1.21a
RS Mulch	6.44b	1.67	0.14a	2.60	0.24	1.08b
F-test	**	NS	**	NS	NS	**
CV%	0.3	8.9	12.5	35.9	12.3	8.7

Apparent carbon balance under tillage methods and rice straw management practices after harvesting of 5th T. Aman rice crop, 2012 are presented in Table 28. From the Table

it is shown that the total organic carbon status (0-20 cm layer) in initial soil was 31 t/ha. After harvesting of 5th T. Aman rice crop the total organic carbon content in soil varied from 26 t/ha (Traditional tillage X control treatment) to 36 t/ha (Traditional tillage X RS mulch treatment). The significantly highest total organic carbon content in soil (36 t/ha)

Table 28: Apparent carbon balance under tillage methods and rice straw management practices (2012)

Treatment		C input (t/ha/2.5 yr)			C output (t/ha/2.5 yr)			C balance (t/ha/2.5 yr)
Tillage	RS mangt.	Initial soil C	Added C (RS applied and RR in situ)	Total	Emission*	Residual	Total	
Min. tillage	Control	31	2	33	5.05	32ab	37	- 4
	RS Incor.	31	12	43	5.51	31b	37	6
	RS Mulch	31	12	43	5.51	33ab	39	4
Trad. tillage	Control	31	2	33	5.05	26c	31	2
	RS Incor.	31	12	43	5.51	33ab	39	4
	RS Mulch	31	12	43	5.51	36a	42	1
F-Test				--		**		
CV%				--		6.7		

*Note: It is the sum of Boro and T. Aman seasons

was observed in Traditional tillage X RS mulch treatment which was statistically identical to the treatment “Traditional tillage X rice straw incorporation (RS incor.)”, “Minimum tillage X rice straw surface mulch (RS mulch) and Minimum tillage X control and the lowest (26 t/ha) was in the Traditional tillage X control treatment which was lower than initial soil (Table 28). From the result it is concluded that the total organic carbon content in soil is significantly built up when rice straw is applied as rice straw surface mulch following Traditional tillage method.

From the Table 28 it is shown that the higher positive magnitude of C-balance was found in those treatments where rice straw was applied irrespective of tillage and rice straw management methods. It varied from -4 (Minimum tillage X control) to 6 (Minimum tillage X rice straw incorporation) (t/ha/2.5 yr).

Effect of tillage operations and rice straw management practices on rice grain, straw and root yield (2010-2013)

T. Aman season

The effect of tillage methods and rice straw management practices on the grain, straw and root yield at maturity stage of T. Aman rice 2010, 2011& 2013 was not significant (Table 29). These results are supported by the result of Tran Quang Tuyen and Pham Sy Tan, 2001. On the other hand in T. Aman rice 2012, tillage methods and rice straw management practices showed significant effect only on straw yield (Table 29). Traditional tillage method produced significantly higher straw yield (4.56 t/ha) than minimum tillage method (4.18 t/ha). Rice straw surface mulch (RS mulch) produced significantly highest straw yield (4.85 t/ha) followed by control and rice straw incorporation (RS incor.).

The interaction effect of tillage methods and rice straw management practices was found non-significant on the grain yield of T. Aman rice in most years of the conducting experiment except 2011 (Table 30). In T. Aman 2011, the highest grain yield (3.99 t/ha) was obtained with the treatment “Minimum tillage X rice straw surface mulch (RS mulch) and the lowest was in “Traditional tillage X rice straw incorporation (RS incor.)” but it was identical to the treatments Minimum tillage X control, Minimum tillage X RS incor., Traditional tillage X control, Traditional tillage X RS incor. and Traditional tillage X RS mulch.

The positive interaction effect of tillage methods and rice straw management practices was found on straw yield of T. Aman rice in 2011 & 2012 while in 2010 & 2013 it was non-significant (Table 30). In T. Aman 2011, the significantly highest straw yield (5.10 t/ha) was obtained with the treatment “Traditional tillage X RS mulch” which was statistically identical to the treatment “Traditional tillage X RS incor.” and “Minimum tillage X control” (Table 30) and the lowest straw yield (3.97 t/ha) was obtained with the treatment “Traditional tillage X control”. In T. Aman 2012, the significantly highest straw yield (5.04 t/ha) was obtained with the treatment “Minimum tillage X RS mulch” which was statistically identical to the treatment “Traditional tillage X RS incor.”, “Traditional tillage X RS mulch” and “Traditional tillage X control” (Table 30) and the lowest straw yield (3.66 t/ha) was obtained with the treatment “Minimum tillage X RS incor.”.

Table 29: Effect of tillage method and rice straw management on rice grain, straw and root yield of T. Aman, 2010-2013.

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Root yield (t/ha)
2010			
Tillage method			
Min. tillage	3.69	6.30	0.39
Trad. tillage	3.71	6.43	0.41
F- Test	NS	NS	NS
CV%	7.4	7.6	11.8
Straw management			
Control	3.62	6.61	0.40
RS Incor.	3.83	6.32	0.39
RS Mulch	3.64	6.17	0.41
F- Test	NS	NS	NS
CV%	7.4	7.6	11.8
2011			
Tillage method			
Min. tillage	3.70	4.64	1.32
Trad. tillage	3.57	4.58	1.35
F- Test	NS	NS	NS
CV%	6.5	5.6	14.5
Straw management			
Control	3.66	4.53	1.38
RS Incor.	3.51	4.53	1.31
RS Mulch	3.74	4.78	1.33
F- Test	NS	NS	NS
CV%	6.5	5.6	14.5
2012			
Tillage method			
Min. tillage	3.52	4.18b	1.23
Trad. tillage	3.64	4.56a	1.24
F- Test	NS	*	NS
CV%	6.9	8.1	10
Straw management			
Control	3.47	4.14b	1.24
RS Incor.	3.79	4.11b	1.19
RS Mulch	3.48	4.85a	1.27
F- Test	NS	**	NS
CV%	6.9	8.1	10
2013			
Tillage method			
Min. tillage	3.41	4.99	1.75
Trad. tillage	3.38	4.56	1.71
F- Test	NS	NS	NS
CV%	6.8	9.4	17.5
Straw management			
Control	3.48	4.63	1.65
RS Incor.	3.35	4.67	1.77
RS Mulch	3.35	5.02	1.78
F- Test	NS	NS	NS
CV%	6.8	9.4	17.5

Table 30: Interaction effect of tillage method and rice straw management on rice grain, straw and root yield of T. Aman 2010-2013

Treatment		Grain yield (t/ha)	Straw yield (t/ha)	Root yield (t/ha)
Tillage method	Rice straw management			
2010				
Min. tillage	Control	3.45	6.41	0.38b
	RS Incor.	3.92	6.42	0.45ab
	RS Mulch	3.70	6.07	0.34c
Trad. tillage	Control	3.78	6.80	0.42abc
	RS Incor.	3.75	6.22	0.33c
	RS Mulch	3.59	6.27	0.49a
F- Test		NS	NS	**
CV%		7.4	7.6	11.8
2011				
Min. tillage	Control	3.53b	5.08a	1.41
	RS Incor.	3.59ab	4.38bc	1.22
	RS Mulch	3.99a	4.46b	1.34
Trad. tillage	Control	3.80ab	3.97c	1.34
	RS Incor.	3.43b	4.68ab	1.40
	RS Mulch	3.49b	5.10a	1.31
F- Test		*	**	NS
CV%		6.5	5.6	14.5
2012				
Min. tillage	Control	3.22	3.83b	1.22
	RS Incor.	3.84	3.66c	1.14
	RS Mulch	3.50	5.04a	1.33
Trad. tillage	Control	3.72	4.46ab	1.26
	RS Incor.	3.74	4.56a	1.25
	RS Mulch	3.45	4.66a	1.22
F- Test		NS	*	NS
CV%		6.9	8.1	10
2013				
Min. tillage	Control	3.44	4.94	1.53
	RS Incor.	3.40	4.95	1.92
	RS Mulch	3.39	5.08	1.81
Trad. tillage	Control	3.52	4.32	1.77
	RS Incor.	3.29	4.38	1.61
	RS Mulch	3.31	4.97	1.76
F- Test		NS	NS	NS
CV%		6.8	9.4	17.5

The positive interaction effect of tillage methods and rice straw management practices was found on root yield of T. Aman rice only in 2010 while in 2011, 2012 & in 2013 it was non-significant (Table 30). In T. Aman 2010, significantly highest root yield (0.49 t/ha) was obtained with the treatment "Traditional tillage X RS mulch" which was statistically identical to the treatment "Minimum tillage X RS incor." and "Traditional tillage X control" (Table 30). The lowest root yield (0.33 t/ha) was obtained with the

treatment “Traditional tillage X RS incor.” which was statistically identical to the treatments “Traditional tillage X control” and “Minimum tillage X RS mulch.

Boro season

The effect of tillage methods on the grain yield of Boro rice (2010-11& 2011-12)was not significant (Table 31) but the effect of rice straw management practices on grain yield was significant in both years. From the Table 31 it is shown that in 2010-11 the significantly highest grain yield (5.83 t/ha) was obtained with the treatment control (without rice straw) which was statistically identical to the treatment RS mulch. While in 2011-12 the significantly highest grain yield (5.58 t/ha) was obtained with the treatment control (without rice straw). In both years the lowest grain yield was obtained with the treatment RS incor. & RS mulch (Table 31).

In Boro 2010-11 the effect of tillage methods and rice straw management practices on the straw yield was not significant (Table 31) while in 2011-12 it was significant (Table 31). From the Table 31 it is shown that Traditional tillage produced more straw yield (5.97 t/ha) than minimum tillage (5.73 t/ha). In case of rice straw management practices RS mulch produced the highest straw yield (6.46 t/ha).

On the other hand in case of root yield, the effect of tillage methods and rice straw management practices was not significant in any of the years (Table 31).

The positive interaction effect of tillage methods and rice straw management practices was found on grain yield of Boro rice only in 2011-12 while in 2010-11, it was non-significant (Table 32). In Boro 2011-12, the significantly highest grain yield (5.68 t/ha) was obtained with the treatment “Traditional tillage X control” which was statistically identical to the treatment “Minimum tillage X control” (Table 32). The lowest grain yield (4.82 t/ha) was obtained with the treatment “Traditional tillage X RS incor.” which was statistically identical to the treatments “Traditional tillage X RS mulch” and “Minimum tillage X RS mulch”.

The positive interaction effect of tillage methods and rice straw management practices was found on straw yield of Boro rice in both years (2010-11 & 2011-12) (Table 32). From the Table 32 it is shown that in 2010-11 the highest straw yield (5.30 t/ha) was obtained with the treatment “Minimum tillage X control” and “Traditional tillage X RS incor.” which was statistically similar to the treatments “Minimum tillage X RS mulch”, “Traditional tillage X control” and “Traditional tillage X RS mulch” and the lowest straw

yield was obtained with the treatment “Minimum tillage X RS incor.” which was statistically identical to the treatment “Minimum tillage X RS mulch”, “Traditional tillage X control” and “Traditional tillage X RS mulch”. While in 2011-12 the highest straw yield (6.89 t/ha) was obtained with the treatment “Traditional tillage X RS mulch” and the lowest (5.33 t/ha) was obtained with the treatment “Traditional tillage X RS incor.” which was statistically identical to the treatment “Minimum tillage X control”.

On the other hand in case of root yield, the interaction effect of tillage methods and rice straw management practices was not significant any of the years (Table 32).

Table 31: Effect of tillage method and rice straw management on rice grain, straw and root yield of Boro rice (2010-11 & 2011-12)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Root yield (t/ha)
2010-11			
Tillage method			
Min. tillage	5.20	4.91	2.08
Trad. tillage	5.45	5.12	1.92
F- Test	NS	NS	NS
CV%	9.3	6.0	17.5
Straw management			
Control	5.83a	5.12	2.06
RS Incor.	4.90b	4.99	2.21
RS Mulch	5.25ab	4.93	1.74
F- Test	*	NS	NS
CV%	9.3	6.0	17.5
2011-12			
Tillage method			
Min. tillage	5.24	5.73b	2.14
Trad. tillage	5.20	5.97a	2.11
F- Test	NS	**	NS
CV%	3.0	2.7	11.9
Straw management			
Control	5.58a	5.60b	2.17
RS Incor.	5.07b	5.49b	1.97
RS Mulch	5.01b	6.46a	2.24
F- Test	**	**	NS
CV%	3.0	2.7	11.9

Table 32: Interaction effect of tillage method and rice straw management on rice grain, straw and root yield of Boro rice (2010-11 & 2011-12)

Treatment		Grain yield (t/ha)	Straw yield (t/ha)	Root yield (t/ha)
Tillage method	**Rice straw management**			
2010-11				
Min. tillage	Control	5.57	5.30a	2.14
	RS Incor.	4.99	4.69b	2.30
	RS Mulch	5.04	4.75ab	1.81
Trad. tillage	Control	6.09	4.95ab	1.97
	RS Incor.	4.81	5.30a	2.11
	RS Mulch	5.47	5.11ab	1.68
F- Test		NS	*	NS
CV%		9.3	6.0	17.5
2011-12				
Min. tillage	Control	5.49ab	5.50cd	2.03
	RS Incor.	5.32bc	5.66c	2.17
	RS Mulch	4.91d	6.02b	2.22
Trad. tillage	Control	5.68a	5.70c	2.31
	RS Incor.	4.82d	5.33d	1.76
	RS Mulch	5.10cd	6.89a	2.27
F- Test		**	**	NS
CV%		3.0	2.7	11.9

There was no significant effect of tillage operations, rice straw management practices and interaction of tillage operations and rice straw management practices on SOC (%) after harvesting of 5^{th} crop (T. Aman rice). Similar trend was also found in case of available P and exchangeable K. Rice straw surface mulch released significantly higher amount (4420 kg/ha/114 days) of carbon dioxide over the control (3969 kg/ha/114 days). Total amount of released CO_2 was higher in T. Aman season than that of Boro season. There is no effect of tillage methods on grain yield production that means minimum tillage method might be used in this study area. The total organic carbon content in soil is significantly built up when rice straw is applied as rice straw surface mulch following Traditional tillage method.

Effect of different organic manure and fertilizer management on carbon sequestration under rice–rice cropping pattern

Carbon dioxide emission *(kg CO_2/ha/day)* from rice field

T. Aman season

In T. Aman 2011 carbon dioxide emission was measured after eight weeks of transplanting and continued up to 16 weeks after transplanting. Results are presented in Table 33. From the Table it is shown that there was no significant effect on carbon dioxide emission from rice soils among the tested organic materials. The higher rate of CO_2 emission was found at 15th weeks after transplanting irrespective of all organic materials (Table 33).

In T. Aman 2012 carbon dioxide emission was measured after 1st week of transplanting and continued up to 17 weeks after transplanting. Results are presented in Table 34. From the Table 34 it is shown that the tested organic materials showed significant effect on carbon dioxide emission from rice soil at 1st to 7th weeks after transplanting and at the rest weeks were insignificant. The higher rate of CO_2 emission was found at 9th weeks after transplanting irrespective of all organic materials (Table 34). Among the tested organic materials the rate of CO_2 emission was higher in cow dung and poultry manure treated plots. CO_2 emission was less in STB fertilizer application treatment compare to organic materials treatment and the lowest was in control treatment.

In T. Aman 2013 carbon dioxide emission was measured after 1st week of transplanting and continued up to 15th week after transplanting. Results are presented in Table 35. From the Table 35 it is shown that the tested organic materials showed non significant effect on carbon dioxide emission from rice soil except 1st week after transplanting. The higher rate of CO_2 emission was found at 15th week after transplanting irrespective of all organic materials (Table 35). Among the treatments the rate of CO_2 emission was higher in organic manures/residues treated plots followed by control and STB fertilizer application treatment.

Boro season

In Boro 2011-12, carbon dioxide emission was measured after 1st week of transplanting and continued up to 16th week after transplanting. Results are presented in Table 36. From the Table 36 it is shown that the tested organic materials showed significant effect on carbon dioxide emission from rice soil at 1st to 4th, 8th to 11th and 14th to 16th week after transplanting. Among the treatments the rate of CO_2 emission was higher in poultry

manure treated plots followed by cow dung treated plots, STB fertilizer application treatment and control.

Cumulative CO_2 (kg/ha) emission from the rice field

T. Aman season

In T. Aman 2011 cumulative carbon dioxide emission was measured after eight weeks of transplanting and continued up to 16 weeks after transplanting. Results are presented in Table 37. From the Table 37 it is shown that there was no significant effect on cumulative CO_2 emission from rice soils among the treatments.

In T. Aman 2012 cumulative carbon dioxide emission was measured after 1st week of transplanting and continued up to 17th week. Results are presented in Table 38. From the Table 38 it is shown that there was significant effect on cumulative CO_2 emission from rice soils among the treatments. Among the treatments the rate of cumulative CO_2 emission from rice soils was higher in organic manures/residues treated plots followed by control and STB fertilizer application treatment during the crop growing period.

In T. Aman 2013 cumulative carbon dioxide emission was measured after 1st week of transplanting and continued up to 15th week. Results are presented in Table 39. From the Table 39 it is shown that there was significant effect on cumulative CO_2 emission from rice soils among the treatments at 1st to 4th and 6th week after transplanting. Among the treatments the rate of cumulative CO_2 emission was higher in organic manures/residues treated plots followed by control and STB fertilizer application treatment during the crop growing period.

Boro season

In Boro 2011-12, cumulative carbon dioxide emission was measured after 1st week of transplanting and continued up to 16th week. Results are presented in Table 40. From the Table 40 it is shown that there was significant effect on cumulative CO_2 emission from rice soils among the treatments from 1st to 16th week after transplanting. Among the treatments the rate of cumulative CO_2 emission was the highest in poultry manure treated plots which were statistically identical to cow dung and rice straw treated plots (Table 40). But the cumulative CO_2 emission was lower in cow dung treated plots compare to poultry manure and rice straw treated plots from 2nd to 7th and 14th week after transplanting.

Table 33: CO_2 (kg/ha/day) emission from the rice field with different organic residues management (T. Aman 11)

Treatment	Weeks after transplanting															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
Abs ctrl	nd	nd	nd	nd	nd	nd	nd	nd	40.48	62.66	52.46	70.32	31.26	49.36	92.11	44.75
CD+IPNS	nd	nd	nd	nd	nd	nd	nd	nd	57.74	70.87	44.59	48.53	35.95	63.70	106.19	47.88
PM+IPNS	nd	nd	nd	nd	nd	nd	nd	nd	52.55	59.72	49.03	45.26	43.08	57.24	118.65	52.96
RS+IPNS	nd	nd	nd	nd	nd	nd	nd	nd	48.19	48.81	46.35	43.83	36.21	51.88	100.91	45.66
STB	nd	nd	nd	nd	nd	nd	nd	nd	45.34	55.26	51.54	38.89	30.76	49.20	74.65	32.76
F-test	nd	nd	nd	nd	nd	nd	nd	nd	NS	NS	NS	NS	NS	NS	NS	NS
CV%	nd	nd	nd	nd	nd	nd	nd	nd	15.8	22.9	12.2	44.5	20.7	28.4	24.3	21.0

Table 34: CO_2 (kg/ha/day) emission from the rice field with different organic residues management (T. Aman 12)

Treatment	Weeks after transplanting																
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17^{th}
Abs ctrl	26.80b	29.96d	28.06b	24.87b	23.21b	36.62b	34.99b	27.28	51.25	25.48	28.89	27.11	37.13	42.41	51.17	12.28	34.03
CD+IPNS	46.31a	52.91a	58.86a	30.82a	28.77a	52.56a	47.56a	38.26	62.90	41.47	33.59	32.39	45.59	47.52	56.78	21.50	43.33
PM+IPNS	43.82a	52.03a	56.32a	30.86a	28.81a	55.20a	46.89a	35.66	65.66	44.04	43.17	40.77	42.91	54.39	58.04	23.17	42.32
RS+IPNS	39.12a	48.66b	55.05a	31.28a	29.20a	50.80a	44.63ab	33.40	63.32	39.64	36.52	35.33	45.68	45.34	57.37	20.66	33.44
STB	24.31b	34.58c	30.31b	25.67b	23.96b	38.96b	35.74b	30.13	52.93	31.28	30.26	28.20	48.44	42.32	51.75	14.21	30.93
F-test	**	**	**	**	**	**	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	14.9	2.4	8.5	6.5	6.5	10.5	12.9	22.7	11.1	20.6	22.5	19.1	23.5	20.1	16.80	36.60	22.50

Table 35: CO_2 (kg/ha/day) emission from the rice field with different organic residues management (T. Aman 13)

Treatment	Weeks after transplanting														
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th
Abs ctrl	35.33b	27.17	34.03	31.30	29.79	31.64	34.24	34.82	31.05	33.93	35.58	39.35	18.77	24.89	43.29
CD+IPNS	46.72a	36.04	46.35	45.38	46.14	49.07	46.56	31.89	41.61	40.90	44.54	45.22	30.21	34.53	49.49
PM+IPNS	46.89a	42.57	60.01	39.18	34.40	54.69	46.64	41.19	35.33	35.62	37.76	44.71	25.62	33.94	52.84
RS+IPNS	48.23a	40.30	38.22	43.04	40.35	47.90	42.28	43.79	42.11	37.71	40.44	41.44	26.11	33.10	41.11
STB	32.06c	32.74	40.56	32.73	33.65	36.33	37.25	35.58	34.49	39.47	42.70	47.56	19.75	27.66	42.03
F-test	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	2.4	16.5	36	28	21.9	21.5	21.6	30.5	16.2	22.4	26.8	17.8	26.3	14	26.4

Table 36: CO_2 (kg/ha/day) emission from the rice field with different organic residues management (Boro 2011-12)

Treatment	Weeks after transplanting															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
Abs ctrl	1.63b	9.18b	10.35b	13.91b	25.77	24.10	37.71	27.28c	33.61c	27.95c	24.26c	35.28	31.09	33.65b	27.33a	35.66b
CD+IPNS	5.66a	10.85b	11.10b	19.28a	36.83	38.43	43.58	44.46a	53.55a	46.64a	36.16a	44.17	36.37	40.35a	30.21a	42.95a
PM+IPNS	8.00a	17.14a	18.90a	29.08a	41.53	41.19	33.19	49.57a	56.57a	49.15a	39.68a	46.93	41.82	45.30a	29.94a	42.70a
RS+IPNS	6.33a	16.30a	20.16a	30.42a	40.94	62.73	41.07	38.26b	48.19b	41.36b	36.08a	43.58	36.79	41.78a	29.45a	40.02a
STB	1.89b	10.77b	10.10b	15.42b	33.65	30.88	35.70	33.31b	43.16b	40.35b	31.05b	33.02	28.33	31.72b	24.84b	32.81b
F-test	*	*	*	*	NS	NS	NS	**	**	**	**	NS	NS	*	**	*
CV%	47.2	19.8	29.7	27.6	18.4	55.8	20.2	10.7	9.3	6.7	6.2	14.6	18.3	11.2	5.4	8.5

Table 37: Cumulative CO2 (kg/ha) emission from the rice field with different organic residues management (T. Aman 2011)

Treatment	Weeks after transplanting															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
Abs. ctrl	nd	nd	nd	nd	nd	nd	nd	nd	283	597	964	1456	1675	2020	2389	2792
CD+IPNS	nd	nd	nd	nd	nd	nd	nd	nd	404	759	1071	1410	1662	2108	2533	2964
PM+IPNS	nd	nd	nd	nd	nd	nd	nd	nd	368	666	1010	1326	1628	2029	2503	2980
RS+IPNS	nd	nd	nd	nd	nd	nd	nd	nd	337	581	906	1213	1466	1829	2233	2644
STB	nd	nd	nd	nd	nd	nd	nd	nd	317	594	955	1227	1442	1786	2085	2380
F-test	nd	nd	nd	nd	nd	nd	nd	nd	NS	NS	NS	NS	NS	NS	NS	NS
CV%	nd	nd	nd	nd	nd	nd	nd	nd	15.8	14.3	12.6	11.2	7.8	9.2	8.4	8.9

Table 38: Cumulative CO_2 (kg/ha) emission from the rice field with different organic residues management (T. Aman 2012)

Treatment	Weeks after transplanting																
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th
Abs ctrl	214b	454b	622b	770b	916b	1136b	1381b	1572b	1931	2135b	2308b	2498b	2758b	3055b	3413b	3499b	3737b
CD+IPNS	370a	794a	1147a	1379a	1609a	1924a	2257a	2525a	2965a	3297a	3498a	3725a	4044a	4377a	4774a	4925a	5228a
PM+IPNS	351a	767a	1105a	1337a	1567a	1898a	2226a	2476a	2935a	3288a	3547a	3832a	4132a	4513a	4919a	5082a	5378a
RS+IPNS	313a	702a	1033a	1271a	1507a	1811a	2124a	2358a	2801a	3118a	3337a	3584a	3904a	4221a	4623a	4768a	5002a
STB	194b	471b	653b	813b	970b	1204b	1454b	1665b	2035b	2285b	2467b	2664b	3003b	3300b	3662b	3761b	3978b
F-test	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
CV%	14.9	6.4	4.4	4.1	4.7	5.5	6.1	7	5.2	6	6.9	7.5	7.2	7.4	7.5	8.2	8.6

Table 39: Cumulative CO2 (kg/ha) emission from the rice field with different organic residues management (T. Aman 2013)

Treatment	Weeks after transplanting														
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th
Abs. ctrl	247b	465b	703c	922c	1131	1352b	1592	1835	2053	2358	2607	2883	2995	3169	3472
CD+IPNS	327a	615a	940ab	1258ab	1580	1924a	2250	2473	2764	3133	3444	3761	3942	4184	4530
PM+IPNS	328a	669a	1089a	1363a	1604	1987a	2313	2602	2849	3169	3434	3747	3900	4138	4508
RS+IPNS	338a	660a	928ab	1229ab	1511	1847ab	2143	2449	2744	3083	3366	3656	3813	4045	4333
STB	224c	486b	770bc	999bc	1235	1489ab	1750	1999	2240	2596	2895	3228	3346	3540	3834
F-test	**	**	*	*	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	2.4	8.2	13	13	14.1	14.6	14.9	15	14.8	14.4	14.7	13.9	14.3	14.1	13.4

Table 40: Cumulative CO_2 (kg/ha) emission from the rice field with different organic residues management (Boro 2011-12)

Treatment	Weeks after transplanting															
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
Abs ctrl	11b	76b	148b	246b	426c	595b	859b	1050b	1285b	1480b	1650b	1897b	2115b	2350c	2706b	2955b
CD+IPNS	40a	116b	193b	328b	586b	855b	1160b	1471a	1846a	2173a	2426a	2735a	2990a	3272b	3665a	3966a
PM+IPNS	56a	176a	308a	512a	803a	1091a	1323a	1670a	2066a	2410a	2688a	3017a	3309a	3626a	4016a	4315a
RS+IPNS	44a	158a	299a	512a	799a	1238a	1526a	1793a	2131a	2420a	2673a	2978a	3235a	3528a	3911a	4191a
STB	13b	89b	159b	267b	503b	719b	969b	1202b	1504b	1787b	2004b	2235b	2433b	2656c	2979b	3208b
F-test	*	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
CV%	47.2	18.2	19.1	18.9	12.7	18.6	14.0	12.5	10.7	9.3	8.6	8.8	8.7	8.4	7.6	7.1

Total CO_2 emissions from the rice field (T. Aman 2012, 2013 & Boro 2011-12)

The total CO_2 emissions from rice soils under different organic residues/manures in T. Aman 2012, 2013 & Boro 2011-12 are presented in Table 41. In T. Aman 2012 & Boro 2011-12, there was a positive effect of different organic residues/manures on the total CO_2 emissions from rice soils while in T. Aman 2013 it was non-significant (Table 41). In T. Aman 2012 among the treatments the total CO_2 emissions from rice soils was the highest in poultry manure treated plots which were statistically identical to cow dung and rice straw treated plots (Table 41). But the lowest was in STB and control plots. Similar trend was also found in Boro 2011-12. From Table 41 it is shown that the total amount of released CO_2 was higher in T. Aman season than that of Boro season. Results might be due to the comparatively higher temperature (Monika *et al.*, 2002) prevails in T. Aman season than Boro season.

Table 41: Total CO_2 emissions from the rice field under different organic residues/manures management, T. Aman 2012, 2013 & Boro 2011-12

Treatment	T. Aman 2012 Total CO_2 emission (kg/ha/119 days)	T. Aman 2013 Total CO_2 emission (kg/ha/112 days)	T. Aman Average Total CO_2 emission (kg/ha/114 days)	Boro 2011-12 Total CO_2 emission (kg/ha/112 days)
Abs ctrl	3737b	3472	3605	2955b
CD+IPNS	5228a	4530	4879	3966a
PM+IPNS	5378a	4508	4943	4315a
RS+IPNS	5002a	4333	4668	4191a
STB	3978b	3834	3906	3208b
F-test	**	NS	---	**
CV%	8.6	13.4	---	7.1

Effect of different organic materials on soil nutrient status

The effect of different organic materials on nutrient contents in soil after harvesting of 5^{th} crop (T. Aman 2012) were found significant on SOC (%), available P and available Zn but the effect was insignificant on soil pH, total N and exchangeable K (Table 42). The significant highest SOC% (1.54) was observed in CD+IPNS treatment and the lowest was found in control plot which was statistically identical to RS+IPNS treatment.

Table 42: Effect of different organic materials on soil nutrient status of the experimental field after harvest of 5th crop

Treatments	pH (1:2.5)	OC%	Total N (%)	Available P (mg/kg)	Exchangeable K (Cmol/kg soil)	Available Zn (mg/kg)
Control	6.4	1.13d	0.13	6.58c	0.22	0.71b
CD+IPNS	6.5	1.54a	0.15	16.95b	0.21	1.27a
PM+IPNS	6.6	1.47b	0.13	53.05a	0.26	1.27a
RS+IPNS	6.4	1.15d	0.13	3.63c	0.22	0.74b
STB	6.4	1.22c	0.13	5.75c	0.22	0.67b
F-TEST	NS	**	NS	**	NS	**
CV%	1.1	3.00	13.2	19.7	13	8.6

The significant highest available P (53.05 mg/kg) was observed in PM+IPNS treatment followed by CD+IPNS (16.95 mg/kg) and the lowest was found in RS+IPNS treatment which was statistically identical to control and STB treatments. The significant highest available Zn (1.27 mg/kg) was observed in CD+IPNS and PM+IPNS treatments and the lowest was found in STB treatment which was statistically identical to control and RS+IPNS treatment.

Effect of different organic materials on grain, straw and root yield

T. Aman season

The effect of organic materials with IPNS based chemical fertilizer on the grain, straw and root yield of BRRI dhan31 were highly significant in T. Aman 2010, 2011, 2012 and 2013 over control (Table 43). In T. Aman 2010, the significantly highest grain yield (4.06 t/ha) was obtained with the treatment PM+IPNS which was statistically identical to CD+IPNS, RS+IPNS and STB. Similar trend was also observed in T. Aman 2013. In T. Aman 2011, the significantly highest grain yield (4.33 t/ha) was observed in the same treatment (PM+IPNS) and the lowest was in control (2.79 t/ha). In T. Aman 2012, the significantly highest grain yield (4.15t/ha) was observed in CD+IPNS treatment which was statistically identical to the treatment PM+IPNS and the lowest was in control. In T. Aman 2010 & 2011, like grain yield of T. Aman 2010 similar trend was also observed in case of straw yield (Table 43). In T. Aman 2012, the significantly highest straw yield (5.40 t/ha) was obtained with the treatment CD+IPNS which was statistically identical to

Table 43: Effect of different organic materials on grain, straw and root yield of T. Aman 2010-2013

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Root yield (t/ha)
2010			
Ctrl	3.20b	3.61b	0.29c
CD+IPNS	3.93a	5.24a	0.36bc
PM+IPNS	4.06a	5.42a	0.50a
RS+IPNS	3.80a	5.45a	0.48ab
STB	3.84a	5.04a	0.48ab
F- Test	*	**	**
CV%	8.6	10.6	19.3
2011			
Ctrl	2.79e	3.93b	0.66b
CD+IPNS	3.95b	5.58a	1.14a
PM+IPNS	4.33a	5.69a	1.22a
RS+IPNS	3.65c	5.51a	1.05a
STB	3.40d	5.40a	1.24a
F- Test	**	**	**
CV%	3.6	10.3	17.0
2012			
Ctrl	2.78d	4.25d	0.93c
CD+IPNS	4.15a	5.40a	1.61a
PM+IPNS	4.00ab	5.25ab	1.63a
RS+IPNS	3.37c	4.81c	1.68a
STB	3.90b	5.10b	1.45b
F- Test	**	**	**
CV%	3.4	4	3.3
2013			
Ctrl	2.99b	4.07b	1.32c
CD+IPNS	3.79a	5.50a	1.48bc
PM+IPNS	3.89a	5.51a	1.78a
RS+IPNS	3.39ab	4.48b	1.56b
STB	3.60a	4.49b	1.40bc
F- Test	*	**	**
CV%	9.6	8.9	5.5

PM+IPNS treatment and the lowest was in control (4.25 t/ha). In T. Aman 2013, the significantly highest straw yield (5.51 t/ha) was obtained with the treatment PM+IPNS which was statistically identical to CD+IPNS treatment and the lowest was in control (4.07 t/ha). In T. Aman 2010, the significantly highest root yield (0.50 t/ha) was obtained with the treatment PM+IPNS which was statistically identical to RS+IPNS and STB and the lowest was in control (0.29 t/ha). In T. Aman 2011, the significantly highest root yield (1.22 t/ha) was obtained with the same treatment like T. Aman 2010 (PM+IPNS) which was statistically identical to CD+IPNS, RS+IPNS and STB and the lowest was in control (0.66 t/ha). In T. Aman 2012, the significantly highest root yield (1.68 t/ha) was

obtained with the treatment (RS+IPNS) which was statistically identical to CD+IPNS and PM+IPNS and the lowest was in control (0.93 t/ha). In T. Aman 2013, the significantly highest root yield (1.78 t/ha) was obtained with the treatment (PM+IPNS) and the lowest was in control (1.32 t/ha).

Boro season

The effect of organic materials with IPNS based chemical fertilizer on grain, straw and root yield of BRRI dhan29 was highly significant in Boro10-11 & 2011-12 (Table 44). In Boro 2010-11, the highest grain yield (5.52 t/ha) was obtained with the STB which was statistically identical to RS + IPNS and CD+IPNS treatments and the lowest in control (3.03 t/ha). In Boro 2011-12, the significantly highest grain yield (5.95 t/ha) was obtained with the STB which was statistically identical to PM+IPNS, RS + IPNS and CD+IPNS treatments and the lowest in control (2.76 t/ha). In Boro 2010-11, like grain yield similar trend was also found in case of straw & root yield (Table 44). In Boro 2011-12, the significantly highest straw yield (5.55 t/ha) was obtained with the treatment RS+IPNS which was statistically identical to STB & CD+IPNS treatments and the lowest in control (2.46 t/ha). Similar trend was also found in case of root yield (Table 44).

Table 44: Effect of different organic materials on grain, straw and root yield of Boro 2010-11 & 2011-12

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Root yield (t/ha)
2010-11			
Ctrl	3.03b	2.99b	0.77b
CD+IPNS	5.34a	5.55a	1.79a
PM+IPNS	3.51b	3.25b	0.95b
RS+IPNS	5.48a	5.60a	1.70a
STB	5.52a	5.80a	1.83a
F- Test	**	**	**
CV%	14.8	16.5	20.0
2011-12			
Ctrl	2.76b	2.46c	0.91c
CD+IPNS	5.77a	5.18ab	1.92b
PM+IPNS	5.44a	4.46b	1.78b
RS+IPNS	5.38a	5.55a	2.43a
STB	5.95a	5.35ab	2.09ab
F- Test	**	**	**
CV%	7.4	13.9	16.6

Apparent carbon balance under different organic materials/residues (T. Aman rice crop, 2012)

The emission of CO_2-C was significantly influenced by sources i.e. residues and manures (Table 45). Though the carbon contents in the rice straw and even in the roots were high, however, the emission of CO_2-C was higher in the poultry manure with IPNS based chemical fertilizer treatment. During the crop growing period (2.5 years) the highest total amount of CO_2-C released from PM+IPNS containing plot was 6.40 t/ha/2.5 yr where as in control plot (without organic manures) it was 4.56 t/ha/2.5 yr and in STB plot it was 4.95 t/ha/2.5 yr (Table 45). The sources of carbon i.e. the residues significantly affected carbon balance (Table 45). When plant residues and manures are applied to the soil various organic compounds undergo decomposition. The addition of residues and manures to the soil surface contributes to the biological activity and the carbon cycling process in the soil. Among the treatments the highest output carbon was found in the treatments PM+IPNS and CD+IPNS and the lowest in RS+IPNS treatment. The lowest amount of output carbon in RS+IPNS treatment might be due to the activity of several generations of different microbes.

Table 45: Apparent carbon balance under different organic materials/residues

Treatment	C input (t/ha/2.5 yr)			C output (t/ha/2.5 yr)			C balance (t/ha/2.5 yr)
	Soil C	Added C (OM applied & rice root)	Total	Emission*	Residual	Total	
Abs ctrl	39	1	40	4.56	29b	34	6
CD+IPNS	39	12	51	6.15	35a	41	10
PM+IPNS	39	12	51	6.40	35a	41	10
RS+IPNS	39	12	51	6.10	27c	33	18
STB	39	2	41	4.95	29b	34	7
F-test	--	--	--		**	--	--
CV%	--	--	--		2.5	--	--

*Note: It is the sum of Boro and T. Aman seasons

Several generations of different microbes in this process die and add carbon in soils. Carbon cycling is the continuous transformation of organic and inorganic carbon compounds by plants and micro and macro-organisms between the soil, plants and the atmosphere. In cultivated organic soils about 450-4500 kg bacteria presents in a hectare-furrow slice, while fungi presents 1120-11200 kg and actinomycetes presents 450-4500 kg (Brady, 2001). Bacteria, fungi, and actinomycetes are 50% of carbon (Boyad, 1995). Therefore, a significant amount of carbon might be added to soils.

11. Research Highlights:

- The soil organic carbon SOC (%) decreased with the increase in soil depth irrespective of land types. The SOC (%) was found higher in the lowland than in the medium highland and highland. The SOC stock (t/ha) at 0-20 cm depth was higher in lowland (except AEZ-1) compared to medium highland and highland soil in irrespective of AEZs. Among the 10 AEZs, the highest SOC stock (t/ha) was found in AEZ-1 irrespective of land types.

- The rate of CO_2 emission was higher in earlier stage of incubation irrespective of organic sources in both flooding and moist condition. However, among the organic materials poultry manure emitted more CO_2 than cow dung, rice straw and rice root alone.
- The SOC (%) decreased slightly with increasing the crop growth duration due to increasing temperature irrespective of all residues and carbon rates. Continuous standing water (CSW) condition was found more efficient to accumulate SOC (%) in soils than AWD.

- The significantly highest total organic carbon stock in soil (36 t/ha) was observed in Traditional tillage X RS mulch treatment. Rice straw surface mulch released higher amount (4420 kg/ha/114 days) of carbon dioxide over the control (3969 kg/ha/114 days) in T. Aman season while in Boro season rice straw incorporation released higher amount (3690 kg/ha/112 days) over the control (3288 kg/ha/112 days).

- Among the organic materials CO_2 emission was higher in cow dung and poultry manure treated plots compared to rice straw treated plot. The total CO_2 emission was highest in poultry manure treated plots (4943 kg/ha/114 days in T. Aman & 4315 kg/ha/112 days in Boro) and the lowest was in control (3605 kg/ha/114 days in T. Aman & 2955 kg/ha/112 days in Boro). Soil organic carbon status in post harvest soil showed slightly increasing trend where organic materials were used compared to inorganic fertilizer treatment except rice straw. Overall PM+IPNS treatment produced higher grain yield both in T. Aman (4.07 t/ha) and Boro season (5.44 t/ha).

Environment and Social Safeguard information

a) Change in environmental situation

Annex-23

Sl. No.	Environmental issue	Component	Baseline				Current status				Remarks
			Small	Moderate	Large	None	Small	Moderate	Large	None	
		Flora			+				+		
		Fauna			+				+		
1		Genetic diversity	+				+				
	Biodiversity	Exotic varieties				none				none	
		Local varieties/ cultivars				none				none	
		Hybrids				none				none	
2		Organic matter			+				+		OC has increased due to application of large amount of OM
	Soil quality	Chemical fertilizer use			+				+		
		Soil salinity				no				no	
		Fertility status			+				+		
		Microbial activity			+				+		
		Heavy metal contamination				no				no	
		Water quality			+				+		
		Pesticide use	+				+				
		POPs				no				no	
3	***Agro-Chemicals***	IPM			+				+		
		Pest infestation				no	+				
		Bio-pesticides				no				no	
		Health hazard				no				no	
		Soil				no				no	
4		Water				no				no	
	Pollution	Air				no				no	

b) Change in social safe guard situation

At the start	Current status	Remark (s)
The projected global warming and climate changes will affect the agriculture of Bangladesh and thereby affect food security and livelihood of the people, particularly the poor. Keeping the view in mind the proposed research is designed to increase carbon in agricultural soils that will increase the quality of soils and thereby increase the crop production. Therefore, the proposed research may contribute to increase food production and thereby ensure food security of the people.	Organic carbon content of the experimental soil has increased due to the application of organic matter. That means it indicates that the quality of soils is increased which might be increased the crop production. It ensures food security of the people.	It indicates the good sign of increase of livelihood of the project area.

Signature: 30.06.14 Name: Dr. Pranesh Kumar Saha

Date: ____________________

12. Major Attainments (in relation to the set objectives):
a. Technical

Sl. No.	Major technical activities performed in respect of the approved objectives	Output (i.e. product obtained: visible/measurable)	Outcome (short term effect of the research)	Impact (long term effect of the research)	Remarks (reason, if anything otherwise plus any other)
1.	Assessment of existing carbon stock in soils of 10 AEZ in Bangladesh	The SOC (%) decreased with the increase in soil depth irrespective of land types and the SOC (%) was higher in the lowland than in the medium highland and highland. The SOC stock (t/ha) at 0-20 cm depth was higher in lowland (except AEZ-1) compared to medium highland and highland. Among the 10 AEZs, the highest SOC stock (t/ha) was found in AEZ-1..			212 samples from two AEZs viz. AEZ-6 & 10 partially were not collected due to delay in fund release.
2.	Carbon accumulation and its mineralization in soils under aerobic and anaerobic condition without rice crop. Soils in combination with different organic materials were incubated under moist & flooding condition.	The rate of CO_2 emission was higher in earlier stage of incubation in both flooding and moist condition and among the organic materials poultry manure emitted more CO_2 than cow dung, rice straw and rice root alone.	During 129 days of incubation the total amount of CO_2 released from soil+PM containing pot was 0.8 g/kg soil, while it was 0.6 g/kg soil under the control treatment.		
3.	Carbon accumulation and its mineralization in soils under aerobic and anaerobic condition with rice crop. Soils in combination with different	The SOC (%) decreased slightly with increasing the crop growth duration due to increasing temperature irrespective of all residues and carbon rates. Continuous standing water (CSW) condition was found more efficient to accumulate SOC (%) in	SOC increased 3.5% in CSW condition than AWD condition at 60 DAT.		

	organic materials were incubated under AWD & flooding condition..	soils than AWD.			
4.	Carbon sequestration in soils under different tillage methods and rice straw management practices in Boro-T. Aman rice cropping pattern.	The highest total organic carbon stock in soil (36 t/ha) was observed in Traditional tillage X RS mulch treatment. Rice straw surface mulch released higher amount (4420 kg/ha/114 days) of carbon dioxide over the control (3969 kg/ha/114 days) in T. Aman season while in Boro season rice straw incorporation released higher amount (3690 kg/ha/112 days) over the control (3288 kg/ha/112 days)	Total organic carbon stock in soil was increased 16% in Traditional tillage X RS mulch treatment than control (31 t/ha).		
5.	Effect of different organic materials and fertilizer management on carbon sequestration under Rice-Rice cropping pattern in Boro-Fallow-T. Aman rice cropping pattern.	Among the organic materials CO_2 emission was higher in cow dung and poultry manure treated plots compared to rice straw treated plot. The total CO_2 emission was highest in poultry manure treated plots (4943 kg/ha/114 days in T. Aman & 4315 kg/ha/112 days in Boro). Soil organic carbon status in post harvest soil showed slightly increasing trend where organic materials were used. Overall PM+IPNS treatment produced higher grain yield both in T. Aman (4.07 t/ha) and Boro season (5.44 t/ha).	The significant highest SOC% (1.54) built in CD (2.0 t C/ha)+IPNS treated plot compared to control plot (1.13%)		

b. Procurement Status: Capital items procured under the project

Name of the equipments procured	Achievement	Remarks	
		Location of the equipments	**Users**
a) Lab equipment 1. Pipette (Auto) 2. Gel flask 3. Dispenser 4. Sample pot	 2 6 1 2500	Laboratory of Soil Science Division, BRRI, Gazipur.	Scientists
b) Office equipments and /or furniture 1. Laptop 2. Printer 3. Camera 4. GPS 5. Generator 6. Furniture (Table-2, Chair-9, File Rak-1)	 1 1 1 1 1	Laboratory and office of Soil Science Division, BRRI, Gazipur.	Scientists and office staffs

c. HRD/Training : (Not applicable)

Title (e.g Ph.D/Trainings, workshops conducted etc.)	Target	Attainments	No. of participants	Benefit of the higher studies/trainings (application o the learning, productivity enhancement)	remarks (reason, if anything otherwise)

d. Financial

Sl. No.	Major Head	Fund received (Tk)	Expenditure (Tk)	Balance/Unspent (Tk)	remarks (reason, if anything otherwise)
A	Salary & Remuneration	2378417	2378417	0	
B	Research expenses	2502592	2502592	0	
C	Operating expenses	268400	268400	0	
D	Fuel, Oil and Maintenance	202889	202889	0	
E	Workshop/Seminar etc.	0	0	0	
F	Publications & printing	94875	70300	24575	
G	Contingencies	107930	106930	1000	
H	Capital expenses	774954	774954	0	
Total		6330057	6304482	25575	

e. Materials developed /publications made:

Type of material/publication	Title	Number	Remarks (being used by/meant of /any other)
Journal	Assessment of existing soil organic carbon of some AEZs of Bangladesh	1	Researchers, Professors, Students etc.
Bulletin	Total carbon stock (t/ha) at 0-20 cm layer of four AEZs in Bangladesh	1	Researchers, Professors, Students and mass peoples etc.

13. Sub-project auditing (cover all types of audit performed)

Types of Audit (e.g BARC/Implementing agency /FAPAD/World Bank/PCU hired firm/others)	Major observations/issues/objections raised, if any	status of the audit objection at the sub-project end	remarks
FAPAD/PCU hired firm	No raised objection	Satisfactory	

14. Reporting

Report type	**Actual date of submission (s)**	**Total number (s)**	**remarks (reason, if anything otherwise)**
a. Inception report	07.06.10	1	
b. Monthly reports*	18.07.10, 12.08.10, 08.09.10, 06.10.10, 08.11.10, 09.12.10, 06.01.11, 06.02.11, 08.03.11, 08.03.11, 31.03.11, 09.05.11, 05.08.11, 20.09.11, 30.10.11, 16.11.11, 05.12.11, 25.01.12, 14.02.12, 12.03.12, 18.04.12, 20.05.12, 20.06.12, 20.06.12, 02.09.12, 19.09.12, 06.11.12, 21.01.13, 21.01.13, 21.01.13, 19.02.13, 19.02.13, 03.04.13, 13.05.13, 12.06.13, 12.06.13, 20.08.13, 24.09.13, 24.09.13	39	
c. Statement of expdts. (SoE)*	18.07.10, 12.08.10, 08.09.10, 06.10.10, 08.11.10, 09.12.10, 06.01.11, 06.02.11, 08.03.11, 08.03.11, 31.03.11, 09.05.11, 05.08.11, 20.09.11, 30.10.11, 16.11.11, 05.12.11, 25.01.12, 14.02.12, 12.03.12, 18.04.12, 20.05.12, 20.06.12, 20.06.12, 02.09.12, 19.09.12, 06.11.12, 21.01.13, 21.01.13, 21.01.13, 19.02.13, 19.02.13, 03.04.13, 13.05.13, 12.06.13, 12.06.13, 20.08.13, 24.09.13, 24.09.13	39	
d. Quarterly report (s)*	22.12.10	1	
e. Six monthly report*	22.12.10, 19.09.12, 03.04.13	3	

f. Annual Report	23.05.11, 03.07.12, 18.07.13	3	
g. Procurement plan	07.06.10	1	
h. annual research program format	16.11.11	1	
i. Environmental monitoring (Annual basis)	11.11.12	1	
j. Social safeguard status (Annual Basis)	11.11.12	1	
k. Field monitoring report (s)**	28.02.11, 18.09.12	2	

* *Provide all since start to end*
** *Conducted at the local level by implementing agencies*

15. Problems/Constraints:

1. Reporting of the project was too many.
2. Delay of fund disbursement also hampered to implement the project activities in time.

16. Suggestions for future, if any:

1. For gaining more reliable database information it is needed to collect more samples covering more areas of the respective AEZ.

2. To get more authentic information regarding soil carbon stocks it is needed to generate some micro-biological characteristics of the respective soil (microbial biomass carbon, microbial biomass N etc).

3. A detailed study is needed to generate information regarding the fate of applied carbon from long-term use of organic materials under rice-rice cropping pattern.

30.06.14
Signature of the Coordinator/Principal Investigator (as applicable)
Date...
Seal

Dr. Pranesh Kumar Sah
Principal Scientific Officer
Soil Science Division, BRRI Gazip
&
Principal Investigator
Carbon Sequestration in Soils of Banglade
(BRRI component)

Counter signature of the Head of the agency/authorised representative
Date............ 30/6/14 ....
Seal

Jiban Krishna Biswas)
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